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NOTES ON POTTERY CLAYS

THE DISTRIBUTION, PROPERTIES, USES, AND ANALYSES OF BALL CLAYS, CHINA CLAYS, AND CHINA STONE

BY

JAMES FAIRIE, F.G.S.

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THE following Notes were contributed to a high-class technical Journal some years ago by the late JAMES FAIRIE, F.G.S., a painstaking and practical geologist. The literature of this subject is limited, and it is thought that, gathered in this booklet, they will be useful to those handling Pottery Clays.

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NOTES ON POTTERY CLAYS

CLAYS

CHAPTER I

DEFINITION—VARIETIES—PROPERTIES

CLAY is an unctuous, tenacious earth, capable of being moulded by hand, and hardened by fire into permanent form. It is the Anglo-Saxon, *claeg*, derived from the Teutonic verb *kleven*, to stick or adhere, because of the clammy, adhesive quality of the substance, which is one occurring in more or less extensive deposits in almost every country of the world, and very abundantly, and in numerous varieties, in the British Isles. It belongs to the order of oxidised rocks, and forms the argillaceous (Latin, *argilla*—clay) family or group of rocks, and is a soft, opaque, amorphous earth of a dense texture, distinguished from every other by its great tenacity when moistened by water (a very remarkable illustration of which was furnished by the unfortunate results of the meeting of the Royal Agricultural Society at Kilburn in 1879), and, also, by its contraction under, and the great hardness which it acquires by, the action of fire; sufficient, indeed, to give off sparks when struck with a steel. Chemically speaking, clay is essentially a hydrated silicate of alumina; the latter being the oxide of the metal aluminium, as silica is of the metalloid silicon; and these oxides being chemically combined with a certain proportion of water, which is a protoxide of hydrogen, it is obvious that oxygen must enter very largely into the composition of clay—to the extent, indeed, it has been calculated, of upwards of 48 per cent. of its weight.

Clay generally contains various impurities, of which oxide of iron is the chief, and generally also its colouring ingredient. To the presence of this oxide is due the peculiar smell given out by impure clays when breathed upon or wetted, and which is called the argillaceous odour; although it has been, and may be, ascribed also to their being impregnated with vegetable matter: alumina and silica and pure clay being all alike free of it. Common clays have an earthy texture with a dull lustreless fracture, and are soft enough generally to take a mark from the finger nail. H. 1·0 to 1·5; sp. gr. 1·8 to 2·7. Clays are never found crystallised; they are of various colours—brown, yellow, dull blue, green, red, grey, and white in the china clays.

There are perhaps no other substances in nature so indefinite in their composition as clays, which are all mechanical deposits, which, however consolidated, have not been subjected to any indurating or metamorphic action sufficient to alter their structure. They have all been derived from the disintegration and decomposition of rocks, chiefly granitic or felspathic, and necessarily, therefore, contain varying proportions of substances found in such rocks, as lime, potash, soda, magnesia, etc. They possess, from their alumina—a large percentage of which is an essential constituent of all clays—the property of absorbing and retaining, under less than a very high temperature, a considerable proportion of water, and of forming thereby a plastic paste of much tenacity, which is compact, smooth, and ctuous to the touch, and, when dry, easily polished by the r or nail. Potters' and most of the other clays are infusible under any degree of heat, but when they contain an excess of alkalies, these act as fluxes and produce vitrification, or even fusibility. They are not soluble in water, but mix readily with it; indeed, one of the characteristics of clay is its diffusibility in water, in which, although insoluble, it remains suspended longer than any other mineral substance—and part only at a great heat with the last portion of their hygroscopic water, that, namely, with which they are mechanically combined, while that with which their alumina and silica are chemically combined can only be driven off by a nearly red heat.

So numerous are the varieties of clays, that Brogniart, the late eminent director of the Sèvres Porcelain Manufactory, gives a list[1] with the analyses of no fewer than 195—of which 28 are china clays—all of which are made use of in various parts of the world; and Mr. George Maw, F.G.S., in his valuable catalogue of specimens illustrating the clays and plastic strata of Great Britain,[2] gives a list of 123, with descriptions and analyses of many of them. But whatever their composition, one essential property, which determines their being classed as belonging to the clay or argillaceous family, they all possess, viz. plasticity, although they may vary much in the degree in which they possess it.

This property of plasticity may be called peculiar to clay, which appears to be the only substance in the mineral kingdom that possesses it in its natural state. Tomlinson[3] says: "The more I consider this property the more wonderful and inexplicable does it appear. Take a mass of dry clay; it cracks easily and crumbles readily; add to it a certain proportion of water, and it becomes *plastic*—it obeys the will of the artist or the artisan, who can, out of this yielding mass, *create* new forms or perpetuate old ones. Drive off the water at a red heat, and its *plasticity* is for ever lost; *rigidity* takes its place; the clay is no longer clay, but something else. It may be reduced to powder, and ground up with water; but no art or science can again confer upon it its plasticity. All this is very wonderful. There is another fact that is equally so: if we combine the constituents of clay in the proportions indicated by the analysis of some pure type of that substance, we fail to produce plasticity." Tomlinson adds: "That a clear idea of plasticity, and of some of the other mechanical properties of matter may probably be gained by considering them due to variations of the forces of cohesion and adhesion, and by bringing those in their turn under Newton's great law of 'attraction—directly as the mass, and inversely as the squares of the distances';" and in illustrating this he suggests the idea, "that the mechanical properties of matter, such as porosity, tenacity, hardness, brittleness, elasticity, etc., depend upon variations in the attractive force of the molecules, according to the distances apart of such molecules"; and further states, that "the method of arranging the particles of clay, at the precise distance that shall impart plasticity, is one of nature's secrets that we have not yet succeeded in penetrating"; and to the questions—"Why is not a clay artificially formed from pure materials plastic?" or "why cannot we produce plasticity by the synthesis of clay?" the answer is, "that all the conditions of plasticity are unknown, and as yet it has proved beyond man's art or science to produce it." Clays, when dried in the air or not fired too hard, adhere to the tongue, in consequence of their affinity for moisture. Their affinity also for vegetable matter, bitumen, and some metallic oxides, particularly oxide of iron, and for acids and salts, make them very useful in many manufacturing processes.

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[1] *Traité des Arts Céramique*, Paris, 1844, "Atlas of Plates."

[2] *Catalogue of Specimens in the Museum of Practical Geology, illustrative of the Composition and Manufacture of British Pottery and Porcelain*, London, 1876, 3rd ed., Appendix A.

[3] "On the Plasticity and Odour of Clay," by C. Tomlinson, Esq., Lecturer on Science, King's College, London, *Proceedings of Geologists' Association*, vol. i.

Clays are either arenaceous (Latin, *arena*—sand) or calcareous (Latin, *calx*—lime), and there are various earths formed by admixtures of these, of which the following two are universally known, and need only be briefly mentioned here, viz.:—Loam, which is a general but not very definite term, applied to soils that are composed of clay, sand, and vegetable mould, is moderately cohesive, less tenacious than clay and more so than sand, permeable by water, with little or no plasticity, but more or less adhesive when wet, and more brittle when dry than clay. When united with lime, iron, or other metallic oxides, it is fusible at a high heat, and melts into a black, tough cinder. When common salt, saltpetre, phosphates, or sulphates are present it is still more fusible. Some of the more argillaceous loams are used for making the coarser kinds of potters' ware, and for tiles and bricks, and if any soluble salts are present in them these will appear as an efflorescence on the surface of the latter. Agriculturists speak of *light* and *heavy* loams, according to the proportion of clay they contain, and also of *sandy* and *calcareous* loams, according as sand or lime predominates in them. The other is Marl, which is a calcareous clay, that is clay mixed with lime, although clays which do not contain lime are often erroneously called marls. Any soft admixture of clay and lime is a marl; "clay-marl" when the clay predominates, "marl-clay" when the lime is most abundant. There are also "shell-marls," and, in geological nomenclature, "chalk-marls," "lias-marls," and others. A characteristic of a true marl is that when dry, it breaks into small cubical fragments and crumbles down, even to powder, by exposure to the atmosphere.

Shales and clay slates are also argillaceous rocks, and, like the clays, are impure silicates of alumina which have been deposited in marine or—often in the former, as in the case of coal shales—in brackish water, and subsequently indurated by heat and pressure. The former exhibit a laminated structure and are fissile parallel with their bedding, while the latter are fissile in parallel planes *other than* those of their bedding. The difference between clays, marls, and shales is put thus by the late Professor Page: "Clays are massive or plastic, and void of structure; marls are friable or crumbly; shales always exhibit some degree of lamination and fissility, and, being in fact the solidified muds of former waters, they present endless varieties in composition, and are usually defined as calcareous, arenaceous, bituminous, and so forth, according to their predominating ingredients." The clay slates of metamorphosed clay occur in England, chiefly in the Cambrian formation, and are extensively worked in North Wales. They have been formed from the waste of pre-Cambrian rocks, deposited as fine mud or clay, in most cases, at the bottom of a deep sea, the fineness of the sediment forming them proving its having been carried in suspension in water for a considerable distance from land, while the great thickness of the beds proves that the process must have been carried on for an enormous period of time. In other cases, the mud has been deposited in deltas or at the bottom of lakes; and in these a larger amount of sand renders the texture of the plates coarser. After deposition and colouring by the admixture of the various oxides of iron and other colouring ingredients (such as carbon in the case of black slates) to which the various colours of slates—grey, dull blue, purple, green, and black—are due, the beds have been highly indurated and metamorphosed by heat, and vertical, combined with great lateral pressure, by which, with perhaps also some chemico-electrical action, their fissile structure and leavage *across* the original lamination of their beds has been sed, and probably during the process of their upheaval, to the mountain ranges of Wales and Cumberland and other ere they occur.

interesting to give here an analysis of a good f the roofing slates of Wales, showing that their composition is a hydrated silicate of alumina—similar to the common clays—coloured by protoxide of iron. The percentage of oxygen in their various ingredients is also given.

WELSH ROOFING SLATE, sp. gr. = 2·824

Silica	60·50	Oxygen	32·27
Alumina	19·70	,,	9·19
Iron (protoxide)	7·80	,,	1·74
Lime	1·12	,,	0·32
Magnesia	2·20	,,	0·88
Potash	3·18	,,	0·54
Soda	2·20	,,	0·57
Water	3·30	,,	2·71
	100·00		48·22

Of the numerous varieties of clays the undernoted may be considered as coming within the scope of this work on potting materials; they being all extensively used in, and being in fact indispensable to, the prosecution of the potters' business; each of them having its own peculiar properties, and each being available for some special purpose in connection therewith, viz.:—

Brick Clays, used in the manufacture of flower-pots and other articles of common use, and for bricks for the workshops and kilns of the potteries.

Fire Clays, for the manufacture of terra-cotta ware, seggars, covers of slip-pans, where the latter has not been superseded by Needham & Kyte's apparatus, fire bricks for furnaces and flues, and the internal lining of stoves, muffles, and kilns.

CHAPTER II

BRICK CLAYS—COMPOSITION AND PROPERTIES

BRICK clays are impure hydrated silicates of alumina, and are chiefly superficial deposits, which are very widely distributed in beds covering extensive areas in nearly all parts of the United Kingdom; either as alluvial lake or river-valley deposits, or as estuary silts and marine beds. Brown loamy clays, which contain but a small percentage of argillaceous earth, are largely used for making common bricks, and are hence called brick-earths; but bricks are made of clays of very varied composition, according to the purposes for which they are required, or their occurrence in the localities where they are wanted. The most extensive deposits of brick clays are those practically inexhaustible beds of what is sometimes called "glacier detritus," the thick deposits of clays of the glacial or immediately post-glacial period. In geological classification the term brick-clay is often used in contra-distinction to that of boulder-clay; meaning by the former, those finely laminated clays of the Pleistocene epochs, which overlie the unlaminated beds of the true boulder-clay or till, and have evidently been formed from it by the wasting and re-assorting agency of water. Clays suitable for bricks, and other "clay wares," are, however, found to a greater or less extent in nearly all the various geological formations, from the older Palæozoic to the most recent; but increasingly indurated as they recede in time from he latter, until, as in the case of the clay slates, they have, ugh the pressure and metamorphic action to which they subjected, acquired a slaty structure, and have entirely lost all plasticity. In various outcrops and beds of the tertiary and underlying formations down to the carboniferous, and occasionally even in older ones, clays of economic applicability (*vide* Mr. Maw's list) occur not merely in a soft and plastic state, but in every gradation between these and hard metamorphic rocks, and many of the most valuable clays occur in a semi-indurated condition, are mined by blasting, and brought to the surface in hard rock-like masses. However compact and hard such clays may have become, they are by "weathering" disintegrated and reduced, after being ground and mixed with water, to their original plastic condition. The durability of bricks and tiles is much increased by allowing the clay to lie mellowing for a year or two before it is used. Common brick clays consist generally of coarse and irregular mixtures of pure clay with sand, iron, calcareous and magnesian earths, mineral alkalies, carbonaceous matter, and various other accidental impurities; many of them, however, are of fine texture and comparative purity, but these are generally extremely local, and are used for special purposes. For brickmaking, clays generally—especially when of stiff and dense texture like the London and the glacial clays—require considerable additions of coarse sharp sand and coal-breeze or ashes, which are indispensable for making good bricks; but the proportion of sand admits of great diversity, varying according to the relative proportions of the siliceous and aluminous constituents of the clays. Ansted says: "That the admixture of a percentage of silica sand, which results in a combination that contains as much as 90 per cent. of silica, is not at all incompatible with the formation of an excellent brick." It is the alumina, however, that renders them refractory, and not the silica, as is often erroneously supposed; for while *pure* silica, like alumina, can stand any amount of heat without fusing, its readiness to combine with the alkaline ingredients which all these clays contain to a greater or less extent—but which in good brick clays ought not to exceed 2 per cent.—is very apt to result in vitrification or fusing of the bricks. Indeed, from over-firing and the presence of an excess of iron and alkaline earths or alkalies in the clay, bricks are frequently fused together or run into a mass of glassy slag, showing often a bright conchoidal (Gr. *koncke*, a shell, and *eidos*, form) fracture. Iron, unless in excess, is not prejudicial, but when in excess, and lime is present, vitrification is apt to be produced, and the tendency to it is increased by the metallic alkalies in the clays. When clay contains too large a proportion of calcareous earth, lime will be produced by burning, and the bricks made from it will soon moulder when exposed to the atmosphere. The alumina of the clay does not melt, but its particles are cemented by the glassy products of the silica and fluxes; when it is in excess there will be a corresponding increase of shrinkage from its dehydration in firing; complete vitrification also produces great contraction in the bricks—most, however, with clays of fine texture, less, when they are coarse and containing a large proportion of sharp sand or other gritty ingredients. In firing, the shrinkage of brick clay may average about 10 per cent., but the degree of contraction is very various, and does not altogether depend upon the purity of the clay; when newly dug the contraction is less than it is when the clay has been well weathered. These clays vary in colour according to the character of the formations in which they occur, and the proportion of iron or other colouring ingredients they contain, and are found of all shades of brown, grey, or black, to yellow, blue, and red. They burn white when entirely free of iron, which, however, is rarely the case. When iron is present they burn to various shades of red—pale, dull, dark, or bright red—the depth of colour depending both on the percentage of iron present and the degree of heat to which they are subjected, the brightest shades of red and buff being produced with but a partial vitrification of the body; complete vitrification modifying the colours considerably. A large proportion of carbonaceous matter affects the colour by arresting the peroxidation of the iron, as does also the alkalies, and still more so the alkaline earths, lime and magnesia. The clays coloured yellow by the hydrous sesquioxide of iron do not produce yellow or buff bricks, owing to being deprived in firing of their constituent water, to which that colour is due, and which is thereby changed to anhydrous red. Grey clays containing less than 1 or 1½ per cent. of iron produce various shades of cream colour and buff bricks, while those containing from 2 to 10 or 12 per cent. of iron produce yellowish fawn to dark reds. Red clays containing from 3 to 4 per cent. of iron produce the bright red bodies used in the manufacture of red terra-cotta ware, encaustic tiles, etc.; but anyone interested in the composition of clays and their colouring ingredients may obtain further and much valuable information from Mr. Maw's list of the "Clay and Plastic Strata of Great Britain," previously referred to, and which the writer has drawn upon for some of the above details—especially those regarding the colouring ingredients of these clays.

Mr. Maw mentions having found by experiment that "five per cent. of caustic magnesia mixed with red clay entirely destroys its red colour in the kiln, probably from the production of a pale-coloured double silicate of iron and the alkaline earth; a familiar example of which reaction occurs in the process of manufacturing yellow bricks in the neighbourhood of London, the colour of which is dependent on the admixture of ground chalk with the brick-earth, which itself burns of a red colour."

Professor Donaldson states that clays containing silica and alumina in the relative proportions of eighty-six parts of the former to fourteen of the latter are the best for brick-making, but the under-noted analysis of four good brick clays shows that the composition of these admits of great variation; and, indeed, any approaching the above composition are of rare occurrence: a fourth of alumina to a half of silica in the clay, and with small percentages of alkaline ingredients, is a good standard, to which No. 4 most nearly approximates.

	No. 1.	No. 2.
Silica and sand	64·14	61·09
Alumina	13·54	19·91
Oxide of iron	7·57	6·75
Lime	1·90	3·36
Alkalies	1·54	2·83
Water and various impurities	11·31	6·06
	100·00	100·00

	No. 3.	No. 4.
Silica and sand	66·16	53·95
Alumina	16·08	25·55
Oxide of iron	8·38	8·06
Lime	1·88	0·68
Alkalies	1·83	1·54
Water and various impurities	5·67	10·22
	100·00	100·00

Although bricks, when made, are generally well dried in the air before being placed in the clamp or kiln, they retain a large amount of moisture, and the first result of burning them is its evaporation, accompanied by that of carbonic acid, which imparts such a heavy and offensive quality to the fumes from brick burning, arising from the calcining of the lime in the clay and the combustion of the coal-breeze or ashes.

When thoroughly burned, the bricks or other "clay-wares" become permanently hard, and cannot by any possibility become again plastic or capable of being mixed with water; they are,
ver, porous, and readily absorb more or less moisture
g to their composition, and the degree of heat to which
been subjected in burning. Pulverised burnt bricks,
clay technically called "ballast," are good
ated clay.

Clay, unmixed with siliceous ingredients, will not make durable bricks or vessels. The purer the clay, the more will it crack or split in drying; and deep clay soils will thus open in chasms of considerable width and depth; but with a proper admixture of siliceous materials, even when only hardened by the hot sun of tropical countries, clay vessels will retain their shape without cracking, and they, as well as similarly composed and sun-dried bricks, will resist for an enormous time, not merely atmospheric influences, but even the solvent power of water. Unless completely vitrified by burning, however, clay vessels cannot be made non-absorbent of moisture without a glaze of some sort, as witness the unglazed porous water-bottles so largely manufactured in England, and so universally made and used in Oriental countries, the coldness of the water in them being produced by its evaporation through the bottles and its condensation on the outsides. Vessels of pottery were probably made of clay, hardened by the sun, long anterior to the making of sun-dried bricks, and very early in the existence of at least the Adamic race of mankind; and such vessels are still made in the East. Sun-dried bricks were also, however, made in very early times, and the walls of houses were built of clay thus hardened—a reference to which is obviously made in what is probably the most ancient book extant—Job (*vide* ch. iv. 19), "How much less in them that dwell in houses of clay." It is also evident from the fact of the Israelites, during their bondage in Egypt, using straw in brick-making, that the bricks they made for Pharaoh were only sun-hardened; that this was not from ignorance of the process of burning bricks, but, probably, to save the unnecessary cost of burning them, where in the hot and almost rainless climate of that country the sun-dried bricks were sufficiently durable, may be inferred from the fact that the Tower of Babel had been built upwards of 600 years previously, of fire-burned bricks (*vide* Genesis xi. 3, where the builders of that monument of man's folly are represented as saying, "Go to, let us make bricks, and burn them thoroughly"), and doubtless fire-burned pottery was also thus early made. From Job ch. ii. 8, "And he took him a *potsherd* to scrape himself withal," it may be inferred that in the early days in which Job lived it was not only made, but broken as well—a practice the continued prevalence of which is by no means of trifling importance to the interests of the pottery trade. It appears also from other ancient records, and from the numerous specimens dug from the ruins of Babylon and other long-destroyed cities of the East, that these clays were used very extensively from the most remote antiquity for an immense variety of articles—domestic vessels of all sorts, seals (mentioned also in Job, *vide* ch. xxxviii. 14, "As clay to the seal"), and cylinders, tablets, and bricks, on which records of events, royal mandates, contracts of sale, and other documents—the preservation of which was necessary—were inscribed, and remain perfectly legible to this day. Many of these may now be seen in the galleries of the British Museum: but although they remained in perfect preservation for thousands of years in the dry climate of the East, and not exposed to atmospheric action even there, owing to their being buried in the sand mounds, which for so long concealed the ruins of these ancient cities, it was found necessary to subject them to a baking process before transferring them to the moist climate of England, where otherwise they would soon have been destroyed.

CHAPTER III

FIRE CLAYS—DISTRIBUTION, USES, AND ANALYSES

FIRE clays are also hydrated silicates of alumina, generally freer of impurities than the ordinary brick clays, and are infusible compounds containing large proportions of silica, with but little iron or alkaline ingredients, and therefore capable of resisting very intense and long-continued heat without slagging, vitrifying, or melting, or becoming soft and pasty. Their refractory property is entirely due to the absence of fluxing matters—such as the alkalies, alkaline earths, and oxides of iron, with which the silica is so ready to combine—except in such minute quantities as not to induce vitrification or fusing in the process of burning the bricks or other fire-clay manufactures. Carbons and hydrocarbons are not unfrequently present in these clays, but the presence of carbonaceous matter (speedily consumed in the kilns) does not affect their refractoriness. Jukes says that in good fire clays " it is probable the silica and alumina exist in just that definite proportion which would form a true silicate of alumina." Fire clays should be of somewhat greasy feel, and it is essential that they should be of uniform texture; they vary much in composition, but have been classed in three qualities, of which the first and purest is used chiefly for the large melting-pots for glass-making; the second, for crucibles used in melting metals and refining steel; and the third, for fire bricks and other ordinary fire-clay wares.

Fire clays are very abundant in the British Isles, and occur chiefly in the Coal Measures underlying the coal seams, owing to which they are called the under-clay or seat-earth of the coal. The coal seams almost invariably rest on a comparatively pure argillaceous bed, and, from the amount of carbonaceous matter it contains, and the abundance in it of the rootlets (*stigmaria*) of the *Sigillaria*, it has doubtless formed the soil in which these and other coal plants grew. In the Dudley coalfield, beneath the ten-yard coal seam and some underlying layers of mixed matter, the fire clay is found of considerable thickness, varying much in quality, the best being found near Stourbridge, 7 or 8 fathoms under the main coal, and is remarkable for its small amount of contraction in firing. When first raised this Stourbridge fire clay is of almost stony hardness and a leaden or slaty-grey colour; it soon however crumbles on exposure to the air, and is then easily softened and tempered with water; it burns to a yellow or ochreous tint. The strata in the neighbourhood of Stourbridge are extremely faulted and shattered, and although lying low in the order of stratification, the fire-clay seams have been upheaved, so as in many places to be got at without very deep sinking. In other places, and in many coal-fields, they occur lower and at great depths, and can only be profitably utilised when raised along with the coal or ironstone with which they are found associated. The Stourbridge clays are raised from seams in the pits varying from 20 to 95 fathoms deep, and averaging about 3 feet in thickness; and, as evidence of the extremes of quality, it may be mentioned that while the ordinary quality is sold for 15s. per ton at the pit mouth, that for crucible making, found in the middle of the seams—known as glasshouse pot clay—sells at 60s. From the analyses, by Prof. F. A. Abel, F.R.S., chemist to the War Office, quoted by Dr. Percy, of nine samples from different pits, the com- sition of these clays varies as follows, viz.:—Silica, from to 67·00 per cent.; alumina, 25·80 to 35·78; iron 1·00 to 6·63; alkaline matter and waste, 0·64 to 3·56 per cent.; and the undernoted two may be taken as of superior quality, viz.:—The first—

Silica	63·40	In this case the clay had been deprived of its water before the analysis was made.
Alumina	31·70	
Iron oxide	3·00	
Alkaline earths and waste	1·90	
	100·00	

The next is one made by Mr. C. Tookey, in the metallurgical laboratory of the Museum of Practical Geology, under direction of Dr. Percy, and quoted in the *Catalogue of British Pottery and Porcelain*:—

Silica	65·10
Alumina	22·22
Proto-oxide of iron	1·92
Lime	0·14
Magnesia	0·18
Potash	0·18
Phosphoric acid	0·06
Organic matter	0·58
Water, combined	7·10
,, hygroscopic	2·18
	99·66

The refractory property of these, or any clay, is least affected by magnesia, more so by lime, still more so by iron oxides, and most of all by potash, while an excess of sand is most prejudicial to plasticity.

Fire clays are very abundant in the Coal Measures of Durham and Northumberland, and are found in seams from 1 to 5 or 6 feet in thickness; the best qualities are obtained from those underlying the coal used for coking and manufacturing purposes. The undernoted analyses are from samples taken from mines a few miles west of Newcastle, belonging to one firm, and show wide ranges of variation :—

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
Silica	51·10	47·55	48·55	51·11	71·28	83·29	69·25
Alumina	31·35	29·50	30·25	30·40	17·75	8·10	17·90
Iron oxides . . .	4·63	9·13	4·06	4·91	2·43	1·88	2·97
Lime	1·46	1·34	1·66	1·76	2·30	2·99	1·30
Magnesia	1·54	0·71	1·91	trace			
Water, organ. matter, and waste . . .	9·92	11·77	13·57	11·82	6·24	3·74	8·58
	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Of these Nos. 1 to 4 will be found, from their large proportions of alumina and water, to shrink more than the others, of which No. 6 will contract least in firing.

Fire-clay goods are used now so very extensively, and for so many purposes, that the possession of such a series of beds as the above, which the Newcastle Coal Measures yield, gives great advantages to manufacturers, enabling them to select and mix their clays so as best to adapt them for specific uses; and the circumstance of these clays being found in great abundance and capable of being more economically worked and manufactured on Tyneside than, perhaps, in any other part of the United Kingdom or of Europe, may account for the extensive business now done there in fire-clay goods, from bricks to gas retorts, and of articles both numerous and of great variety for building and manufacturing, sanitary, and ornamental purposes. The great heat required to vitrify drainage pipes insures their being thoroughly burnt, and enables them more efficiently to resist corroding and chemical action. Some of these have been tested to sustain a pressure of from 80 to 120 lb. on the uare inch, and when well burnt and glazed they are prac- lly imperishable. Samples from Glasgow, Dowlais, Cool tannington, and Howth show the undernoted maximum and minimum percentages of the principal ingredients:—Silica, from 43·00 to 67·96; alumina, 21·18 to 40·09; iron oxide, 1·19 to 8·4; water and various matters, 3·14 to 15·10 per cent. The Glasgow (Garnkirk) fire clay is of very superior quality, as may be seen from the following analyses of two samples:—

Silica, 66·68; alumina, 26·08; lime, 0·84; iron oxide, 1·26; water, 5·14 = 100·00. Silica, 65·20; alumina, 33·41; lime, 0·32; magnesia, 0·13; iron oxide, 0·49; phosphates, 0·45 = 100·00. Specific gravity, 2·358.

A variety of fire clay occurs at Dinas in the Valley of Neath, Glamorganshire, which consists of nearly pure silica, and which Dr. Siemens states he has found to be the only material practically available on a large scale for bricks or furnace lining, to resist the extreme heat (4000° Fahr.) for melting steel. The celebrated Dinas fire bricks possess the peculiar property (as compared with other clay wares) of expanding instead of contracting under heat, which renders them more suitable for some special purposes than any other.

In Staffordshire there is an abundance of fire clays in the Coal Measures, which are locally called marls, and are extensively used for making the seggars in which the pottery wares are fired. The marl is mixed with old ground seggars, and stands very well the heat of the biscuit kilns in firing ordinary earthenware, but it is inferior to the fire clays used by French porcelain manufacturers, and would not be sufficiently refractory for firing the superior hard porcelain wares now made in Staffordshire, but for the fact that oxidising firing is employed, whereas, on the continent, the firing must be reductive. The Nungarrow porcelain made in Wales some sixty or seventy years ago—specimens of which from their superior quality now command high prices—was made of a most refractory body, and required the sacrifice of the seggars in which it was fired, as, owing to the extreme heat necessary for its conversion, they were useless for a second firing. The following is an analysis of a marl used for seggars in Staffordshire, viz. :—

Silica	66·16	The quantity of iron oxide and lime which it contains reduces of course its refractoriness.
Alumina	22·54	
Iron oxide	5·31	
Lime	1·42	
Magnesia	trace	
Water and loss	4·52	
	99·95	

A leading Stourbridge firm gives the undernoted analyses of two qualities, and they state that they can supply the purest fire clays in the world :—

No. 1.

Silica	73·51
Alumina	21·89
Oxide of iron	0·53
Lime and magnesia	1·59
Loss on ignition	2·48
	100·00

No. 2.

Silica	68·91
Alumina	28·92
Oxide of iron	0·23
Lime and magnesia	0·78
Loss on ignition	1·16
	100·00

Another firm gives the following analysis of their best Stourbridge glasshouse pot clay :—

Silica	66·35
Alumina	23·50
Oxide of iron	1·54
Lime	0·39
Magnesia	0·12
[illegible] and organic matter	8·10
	100·00

They also give the undernoted analysis of their best black crucible clay :—

Silica	45·29
Alumina	35·27
Oxide of iron	2·36
Organic matter	1·64
Lime	0·15
Magnesia	0·08
Alkalies	0·40
Water	14·81
	100·00

CHAPTER IV

POTTERY CLAYS—PIPE CLAY

OF pottery clays — so called because suitable for the manufacture of pottery wares—the distribution is very wide and the origin very various. They are embraced in the French term *figuline* (Lat., *figulus*, a potter, from *fingo*, to fashion). The purest varieties are white or light-bluish grey, are very plastic, and are chiefly found in the superior beds of the more recent geological formations. The Eocene clays of the Paris basin, which immediately underlie the Eocene clay of the London basin, so well known as the "London Clay," received the name of *argile plastique* originally in France, says Lyell, from its being much used there for pottery wares. Beds of the same age (the Woolwich and Reading series of Prestwich) are largely used for the same purpose in England. "As a series," says Page, "these plastic clays constitute the middle portion of the Eocene group. They are partly of marine and partly of fresh-water formation, and are characterised by two species of oyster (*Ostrea bellovacina* and *O. edulina*), and some fresh-water shells, as *Melania*, *Cyrana*, *Unio*, *paludina*, etc." These clays, like those more common and impure varieties already described (*vide* Chaps. I. and II.), are all more or less pure hydrated silicates of alumina. They are found very generally all over the world, and very abundantly in many districts of England and Wales, and of Scotland. They occur also in reland—a country rich in mineral deposits of every sort, and the raw materials for mining and manufacturing industries, which only awaits the development of these to become a perfect hive of busy labour, and the seat of wealth-producing arts and manufactures—although from the unhappy causes which conduce so effectually to prevent the investment of capital, and the suppression of industrial enterprise there, its rich deposits of mineral wealth still lie neglected and unworked.

These clays occur of very varying composition, quality, and colour, the latter ranging from white, yellowish-white, and greys of various tints, to brown, yellow, green, red, and black. With the exception of the last — which is due to the presence of organic, carbonaceous, or bituminous matter, and is in most cases burned out of the clay in firing, leaving the biscuit ware perfectly white—these colours are chiefly derived from various oxides of iron, or, in the case of brown clays, from manganese. They all possess the qualities already mentioned as characterising the argillaceous family of rocks; adhere strongly to the tongue; contract to a greater or less degree in the kiln—often with much irregularity; are more soft, soapy, and plastic than brick clays; and are all, when free from excess of iron, alkalies, or other fluxing ingredients, perfectly infusible, by which is meant that they will not melt or become pasty in the most intense heat of the biscuit kiln, or say 3272° F.—about the melting-point of wrought iron. "All clay at a sufficient heat," says Janvier, "would melt into a sort of glassy substance." That, however, is not so. Perfectly pure clay is practically infusible under any heat; such a clay, however, is of very rare occurrence, and in pottery clays there may be found many varying much in refractoriness according to their contained proportions of silica and fluxing ingredients. Most of them contain larger or smaller percentages of such ingredients, as felspar, iron, lime, magnesia, manganese, mica, potash, soda, and free silica, quartz, or sand. The more alumina a clay contains, and the purer it is, the greater is its refractoriness. With the exception of those containing iron, pottery clays generally burn white in the kiln.

Of the finer kinds of these plastic clays there are numerous varieties, some only suitable for coarse pottery and terra-cotta ware; others for the finer kinds of brown and red ware and tiles; and others again for the best qualities of common earthenware, which embrace the excellent brown and blue ball clays of Dorsetshire, and the black and cracking clays of Devonshire; all of which will be noticed more in detail in these pages.

Of these clays the purest are the well-known pipe clay (so called from its extensive use for the manufacture of tobacco pipes) and china clay or *kaolin*, which will be described in subsequent chapters. The latter of these is generally believed to be derived from the decomposition of the potash felspar (*ortho clase*) in certain kinds of granite, and is at all events only found in the granite districts, chiefly of Cornwall, while pipe clay, which has been called plastic clay, *par excellence*, occurs in extensive deposits in the Miocene and Lower Tertiary beds of Devonshire and Dorsetshire, whence it is largely shipped to the potteries for home manufactures, besides being extensively exported to France, Belgium, Holland, and elsewhere. The composition of pipe clay resembles that of china clay, but it contains an excess of silica. It may be stated as silica 54, alumina 32, water 12, with small quantities of lime and magnesia, etc. It is remarkably free generally from iron; is compact, unctuous, and almost greasy to the touch, and is very pure, plastic, and infusible; when dry, may be polished by the finger. While exceedingly plastic it yet forms a very tenacious paste, and is very absorbent of moisture, and consequently adheres so strongly to the lips, that the ends of the tobacco pipe stems require to be glazed ere they are fit for use. It burns very white, and the best qualities when fired are ntirely free of the yellow or brown spots, which, in the scuit of so many pottery clays, indicates the presence of

lay is applied to many purposes besides the making of pipes, but contracts too much in firing to be available for general pottery purposes, although it is occasionally used for mixing with other clays for some wares. The best qualities are got at Bovey Tracey, in Devonshire, and in the Island of Purbeck, in Dorsetshire. There are two varieties of the Dorsetshire pipe clays, of which one is much darker than the other. Their composition is as follows, both having been first deprived of their hygroscopic water, viz. :—

	Light variety.	Dark variety.
Silica	65·49	72·23
Alumina	21·28	23·25
Oxide of iron	1·26	2·54
Alkaline earths	7·25	1·78
Sulp. of lime	4·72	trace
	100·00	99·80

Ansted gives the following analysis of another variety, viz. :—

Silica	53·66
Alumina	32·00
Iron oxide	1·35
Lime	0·40
Magnesia	trace
Water	12·08
	99·49

Pipe clays are largely used for cleaning and whitening the gloves and leather belts of soldiers, and the common kinds are much used for household purposes, pipe-claying stone steps, window-sills, etc. The finest quality is used for the manufacture of the Cologne pipes.

Pipe clay is found in Ireland, associated with lignite, in the beds of the Lough Neagh series. It lies in a hollow in the carboniferous limestone at Loughloheny and Ballymacadam, south-east of Cahir; and three miles north of Cahir similar clay occurs. These are the remains of a once extensive deposit. Below the lignite beds, this clay is perfectly pure, and has been largely exported to England for the manufacture of the finer kinds of pottery. There are also deposits of pipe clay in Arran island, Co. Donegal, along the shore of Lough Ree, Co. of Roscommon, and especially near St. John's Point, where it is locally largely manufactured into tobacco pipes. Pipe clay also occurs near Blackball, north of Brosna, King's Co., and, in addition to its use for tobacco pipes, it was used by the late Earl of Rosse for lining his furnaces. In an extensive district of Tipperary, between Cahir and Clonmel, there are deposits of pipe clay in the cavities of the lower limestone, which are considered equal in quality to the pipe clay of Bovey Tracey. It burns purely white, and large quantities of it have been exported to England.

CHAPTER V

POTTERY CLAYS—BALL CLAYS—ANALYSES OF PIPE, BLACK, AND BROWN CLAYS

THE varieties of pottery clays are so numerous that anything like an exhaustive list and description of them would far exceed the necessarily limited space available. Those of our readers, however, who may be interested in ascertaining whether any of the native clays, not hitherto much utilised, can be profitably made available for potting or other purposes, will do well to consult Mr. Maw's *Catalogue of the Clay and Plastic Strata of Great Britain*, already referred to and quoted. In that catalogue Mr. Maw gives a list of 123 varieties of pottery clays—ranging from recent alluvial and post-tertiary deposits through all the geological formations down to the Silurian. These clays are of many sorts and of various origin, and differ from each other in composition and purity, in colour, in plasticity, and tenacity, in their degree of contraction in the kiln, and in their refractory qualities. Some of them have already been referred to and described in preceding chapters; in this, attention will be chiefly confined to the ball clays of the Miocene lignite beds of Bovey Tracey, Devonshire—of fresh-water lake formation—and those of Poole, which are found in the Lower Bagshot beds, of middle Eocene age, and which are of marine origin, except the fresh-water deposits in the Island of Purbeck. The Poole clays—so called from their being shipped at that port—form very extensive beds in the neighbourhood of Wareham, Dorsetshire.

The Bovey Tracey beds are of uncertain thickness, and have been estimated to range from 200 to 300 feet in depth. One section, given by Woodward in his *Geology of England*, shows various seams of clays, sands, and lignite, of about 110 feet in all, under the surface drift, and resting on sand—the clay seams being together about 40 feet in thickness. Dr. Miller, in vol. li. of the *Philosophical Transactions*, describes the whole series of strata as dipping to the south about 20 inches in a fathom, and says that including the beds of clay with which they are intermixed—there being about six beds of each—the thickness of the whole is about 70 feet. These clays are very varied in their composition and qualities, and are probably derived from the waste of the neighbouring green-sand formation, and of the granitic rocks of Dartmoor, or, as Mr. Maw suggests, partly from the insoluble matter in the chalk. They consist of some valuable beds of white pipe clay, and of good pottery clays, grey, blue, brown or chocolate-coloured, and black; also that known as cracking clay, from its tendency to crack in firing. The clays are dug from pits, in balls of about 30 lb. weight, at Teigngrace and Whiteway, near Kingsteignton and Newton Abbot, and are shipped from Teignmouth, and thence sometimes called "Teignmouth clays." Mr. Maw[1] quotes Mr. Charles D. Blake, of Newton Abbot, as stating that "the mines there produce clays containing silica and alumina in every proportion, from 95 to 50 per cent. of silica and from 50 to 4 per cent. of alumina"; also "that some of them are nearly pure silicates of alumina, containing no free silica, whereas others contain as much as 70 per cent. of it."

The Lower Bagshot beds of Dorsetshire consist of alternating seams of variously-coloured potting clays and pale yellow or buff-coloured siliceous sands and loams and beds of flint pebbles;

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[1] In a Paper on "The Sources of the Materials composing the White Clays of the Lower Tertiaries," *Quarterly Journal Geological Society*, l. xxiii. pp. 387 to 394.

beneath the potting clay there is a seam of some thickness of an extremely friable earthy brown coal, somewhat analogous to that of the Bovey lignite, but of less specific gravity. It is interesting to note the occurrence of this, characteristic, as this brown coal or lignite is, of the plastic clay tertiary deposits of the Isle of Wight and the London and Paris basin and others. On the north side of the chalk hills, extending from Handfast Point to beyond Corfe Castle, there is an extensive bed of pipe clay in a horizontal position, which has been identified with the lignite clay bed of Alum Bay, in the Isle of Wight. The same seam of clay, though not of equal quality, may be traced in the hills near Poole, and is found in many parts of the extensive track called the "trough of Poole." In a quarry on the borders of Poole Harbour, about 2 miles west of Poole, several beds of the white pipe clay from 3 to 5 feet thick occur, alternating with beds of brown clay, and white, red, and black sand. The Poole ball clays are extensively used for pottery, and are found in beds of various thicknesses and at different depths. They are dug to a great extent, at Creech Grange, Nordon, and Rempstone, between Wareham and Corfe. They are of very superior quality, and consist of white pipe clay and grey, blue, and brown pottery clays. The blue clay contains a little more alumina than that of Devonshire, and is so far superior to it for earthenware manufacture, although in practice the difference is not always perceptible. Other ingredients being equal, the excellence of pottery clays may be determined by the respective percentages of alumina which they contain. Alumina is a light material, while silica is a heavy one, and the specific gravities of these clays may therefore afford an approximate test of their value for earthenware manufacturers. Both the Teignmouth and the Poole clays are remarkably good and plastic and of excellent working quality, and from their comparative freedom from iron and alkalies they are valuable, owing to their refractoriness and their great whiteness when fired. Their specific gravities may be taken as ranging from 1·725 to 2·250. While the better qualities are much used for earthenware and stoneware manufacturers, others are very suitable for flooring-tiles, drain-pipes, and other pottery wares.

These clays generally appear to be derived from the disintegration of other rocks, and the natural separation of their constituent materials by the aid of water and atmospheric influences, which have resulted in local deposits of them—as in the case of steam ore and china clay—which in some places are coarse and impure, in others finer and more or less free of impurities. Some of them are much in request by sculptors and modellers.

In the clays derived from the decomposition of felspars, there is always to be found a considerable quantity of free silica in the form of quartz sand.

The whitest clays are esteemed the purest, but Dr. R. Watson, in his valuable chemical essays,[1] a work which has been highly recommended by Dr. Percy, in his popular lectures on metallurgy in Jermyn Street Museum, states (vol. ii. p. 256) that "I took 16 oz. of the finest pipe clay from Dorsetshire, and by repeatedly washing it in large quantities of water and pouring off the turbid water, I collected a sandy sediment, amounting, when well dried, to 3 oz. I have no doubt that this clay contained a much greater proportion of sand than what I had been able to collect; for the white particles which had been suspended in the water certainly consisted in part of a sand of a finer grain than what had settled to the bottom, for they were sensibly gritty between the teeth. It may easily be conceived that, in washing clays, the finest part of the sand (silica) contained in them will remain suspended in the water, and that, on this account, the sediment collected at the bottom of the vessel in which the operation is performed, will not give the true proportion of the sand which enters into their composition. In confirmation of this, we have been instructed, by the experiments of a very able chemist, to consider these fine white clays as consisting of about three parts in eight of true argillaceous earth, and of about five parts in eight of sand, or earth resembling powdered flints.

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[1] *Chemical Essays*, by R. Watson, D.D., F.R.S., 6 vols. London: vans, 1793.

In contrast to the above, Mr. Maw, in the paper above referred to, states, that "in testing the peculiarly fine state of subdivision of the white tertiary clays of the Bovey Tracey and Wareham beds, I found that, after mixing them with water to the consistency of cream, and passing them through fine silk lawn, containing 10,000 perforations to the square inch, no appreciable quantity of coarse matter remained behind from most of the examples, not even to the weight of a grain out of several pounds of clay," and he adds, "I can state, from the result of a number of experiments on clays and marls of various ages and formations, that such a state of subdivision is peculiar to these tertiary clays."

From these so opposite results, from two competent practical observers, it is evident that all these clays cannot be referred to a similar origin. Mr. Prestwich and many other geologists consider these clay deposits to be derived from the denudation from old crystalline and granitic rocks; Mr. Green, in his book on Geology, says, "from the decomposition of felspathic rocks by carbonated water." Messrs. Pengelly & Heer, at p. 9 of their memoir, "On the Lignite Formation of Bovey Tracey," published in the *Philosophical Transactions*, make reference to "the probable derivation of the deposit from the degradation of the Dartmoor granite"; but Mr. Maw, in quoting their opinion, says that "this inference seems to be due more to the geographical proximity of the granite to the clays of the lignite formation than to any more certain evidence"; and further that "the occurrence of beds of similar physical character and age, far removed from the source of granitic materials, would seem to throw doubt on the suggested local origin from the granite of Dartmoor. Mr. Maw then proceeds to give the evidence which has led him to form the opinion "that the geographical distribution of the white tertiary clays, which are either superimposed on, or in close proximity to, the chalk, suggests their derivation from it rather than from the granitic rocks. Mr. Maw's paper is exceedingly interesting, and well worthy the attention of all interested in the composition and qualities of these clays, but limited space prevents a full résumé of it here. Were all the white clays as free of siliceous material as those he investigated, there would be little difficulty in coinciding with his opinion; but how about those from the same deposits, containing such an excess of silica as those examined by Dr. Watson contained?

Those clays which are so free of siliceous ingredients as those referred to by Mr. Maw will require a much larger admixture of flint in the slip than those tested by Dr. Watson, and such marked differences in the constituent composition of these pottery clays show how foolish the dependence in potting of any mere "rule of thumb" practice of compounding slip bodies must necessarily be, in securing uniformly good biscuit wares.

Pipe Clay.—As supplementary to the analyses of these, the following analysis, by Dr. Voelcker, of white pipe clay from Newton Abbot may be given, as it is quoted by Mr. Maw in confirmation of his opinion of its derivation from the watery dissolution of chalk.

Soluble in hydrochloric acid:—

Moisture and water of combination	9·09	
Oxide of iron	0·50	
Alumina	18·05	
Lime	0·18	
Magnesia	0·14	
	——	27·96

Total soluble in hydrochloric acid		27·96

Insoluble in hydrochloric acid:—

Alumina	18·87	
Lime	0·25	
Magnesia	0·18	
Silica	51·88	
Alkalies and loss	0·86	
		72·04
		100·00

These clays are often of grey or blue colour before exposure to the air, but when so exposed become, from further oxidation, more or less yellow or red.

The following is an analysis of a yellow clay used for coarse ware:—

Silica	58·07
Alumina	27·38
Iron oxide	3·30
Lime	·50
Magnesia	trace
Water, etc.	10·30
	99·55

Black Clay owes its distinctive colour to the quantity of carbonaceous or bituminous matter which it contains; one variety of it, containing 13 per cent. of carbon, burns extremely white, which is caused, Mr. Maw states, "by the reduction of its sesquioxide of iron in the kiln by reaction with its carbonaceous matter." In all these clays the black colouring matter is entirely consumed and dissipated in firing, leaving the biscuit ware of a very good white, and which, indeed, is said to be the whiter in proportion as the clay has originally been blacker. The analysis of a variety of this dark-coloured clay was given in a former chapter as: silica, 72·23; alumina, 23·25 ; oxide of iron, 2·54 ; alkalies and alkaline earths, 1·78 ; loss 0·20 = 100·00. This was an analysis by Prof. Way of a black pipe clay from the Lower Bagshot deposits in the Island of Branksea, Dorsetshire.

Cracking Clay is so called from the tendency it possesses of causing the ware to crack in the biscuit firing. This tendency to cracking may, to a great extent, be corrected by a judicious admixture of other clays and flint, but probably the clay would be little used in potting, owing to the trouble and uncertainty this occasions, were it not for the fact that it produces a biscuit ware of extreme whiteness.

Brown Clay owes its colour to manganese probably. It produces a white biscuit ware, but this has such a tendency to imbibe moisture, that many potters refuse to use this clay at all. The moisture which it imbibes in the biscuit state is parted with only in the glost kiln, and its escape there causes the glaze to craze much. This clay besides will not bear exposure to any great amount of heat, and it is therefore generally only used for black and common red wares.

The following are the analyses of two varieties of it, the first of which is from Dorsetshire :—

Silica	63·00	49·44
Alumina	32·00	34·26
Oxide of iron	3·00	7·74
Lime	—	1·48
Magnesia	1·00	1·94
Water and Loss	1·00	5·14
	100·00	100·00

Blue Clay is decidedly the best of all the ball clays. That om Dorsetshire is preferred to the Devonshire for earthenware and stoneware manufacture, and commands a higher price in the potteries, which may on an average be about an eighth more than the price of the latter. This clay combines the greatest number of good qualities. It produces a very white and solid body of ware. It is capable of being advantageously mixed with a greater percentage of flint than any of the other ball clays or china clay. This not only increases the whiteness of the ware, but produces a better body, and counteracts also, to a great extent, the tendency of the clays which have an excess of alumina in their composition, to shrink too much and crack. Its colour has been attributed to its being derived from the decomposition of the felspar of syenite, a variety of granite in which mica is replaced by hornblende; but if its origin can be proved to be from chalk, its colour must then be attributed to a protoxide of iron. Mr. Maw gives the composition of the Poole clay, so extensively used in the potteries, as silica about 60 per cent., alumina about 34, potash 2, oxide of iron and water about 4 = 100·00.

CHAPTER VI

ORIGIN AND COMPOSITION OF DORSETSHIRE AND DEVONSHIRE CLAYS

IN the previous chapter a quotation is given (p. 28) from Mr. Maw's paper in the *Quarterly Journal of the Geological Society*, in which he quotes Mr. Charles D. Blake, of Newton Abbot, as stating that "the mines there produce clays containing silica and alumina in every proportion, from 95 to 50 per cent. of the former, and from 50 to 4 per cent. of the latter." Now, by referring to the first of these articles on clays, it will be seen that clays are essentially hydrated silicates of alumina—that is, they are composed, when pure, of a chemical combination of silica, alumina, and water—the alumina having the property of absorbing and retaining, under less than a very high temperature, a considerable proportion of constituent water, to which the plasticity of the clay is due. Clays rich in alumina, known as "fat," are thus more liable to cracking and shrinkage than poorer or "meagre" clays; but this tendency is corrected by the presence of a due proportion of silica, clays deficient in the latter requiring, of course, a larger proportion of ground flint mixed with them in the slip to produce a good sound biscuit body. Besides their constituent or chemically combined water, clays are found often containing greater or less percentages of moisture, which is called their hygroscopic water, and which they part with in drying, or at a low heat, while it requires a red heat to deprive them of the former. Now it is evident that any substance containing 95 per cent. of silica, and, say, 4 per cent. of alumina (which is the minimum percentage found in the Newton Abbot mines referred to), could only—supposing them perfectly pure, and thus free of all impurities, such as iron, lime, magnesia, etc., and also quite dry or free of all moisture—have 1 per cent. of constituent water ($95+4+1=100$). As none, however, of these clays are found absolutely pure, but on the contrary have at least from 2 to 4 per cent. of impurities, there cannot be in this case sufficient water to impart plasticity and to constitute clay. It is therefore probable that as the disintegrated material of the rocks from which the deposits in these mines have been derived—whether from the decomposition and waste of the Dartmoor granites or otherwise—have been deposited, owing to the different specific gravities of the silica and alumina, in various beds differing widely in their respective proportions of these materials, that those referred to by Mr. Blake are really deposits of silica, mixed with 5 per cent. of alumina, and iron, lime, or other impurities.

Mr. F. W. Rudley, of the Museum of Practical Geology, in his remarks on the origin and composition of clays (*Catalogue of Specimens*, p. 4), says, that "when the remains of the decomposed felspars are washed into localities where they become mingled with other earthy matters in a finely comminuted state, or when they have been derived from a rock which contains decomposing hornblende, the resulting material is no longer white, but is variously coloured. Even when we suppose the purer varieties to have been deposited in the first instance, and to have formed distinct beds—as, for example, the clays of Bovey Heathfield, in Devonshire, which appear to have been washed, with other detrital matter, and even trees, from the granitic region of a part of Dartmoor in previous geological times—it is easy to see that these clays may be again removed by atmospheric influences, rivers, and other abrading agents, and thus be rendered impure by the admixture of a variety of substances brought into intimate association with them by these causes."

In this way beds of re-deposited clays of very varying composition may occur, more or less widely dispersed, and of varying thickness.

In reference to the Teignmouth clays, De la Beche says:[1]—"These clays" (which he calls supra-cretaceous or tertiary, they having not, when he wrote, been ascertained to be of Miocene Age) "are stated to have been first worked about the year 1730, and would appear to have been formed naturally, much in the same manner as is now done artificially in Cornwall and Devon, though on a larger scale; decomposed granite having been washed down from Dartmoor into a lake or estuary, so that while the grosser particles were first lodged at its higher end, nearest the granite, the fine sediment was accumulated at the lower part."

The Poole clays, Mr. Rudley states (p. 5), "are examples of tolerably pure clays (that is, containing a large proportion of silicate of alumina, with free silica, but without injurious ingredients) which have been accumulated far from any decomposing crystalline rocks, such as granites, porphyries, and the like. . . . Its decomposed felspathic matter, affording the silicate of alumina, and a portion at least of the free silica, may readily have been derived from other beds, such as those of many sandstones, in which that matter may have been disseminated. Prior existing clays may also have been broken up and re-deposited."

As sandstones seldom contain much felspathic ingredients, other than the siliceous, it is more probable that the Poole clays have been derived from the waste of clay-slate rocks—an opinion held by Mr. Robert Hunt, F.R.S., of the *Mining Record* office. These clays appear to have been worked at an earlier date than the Teignmouth clays—at all events they are referred to in an "Order of Council," in 1666, which directs that no dues were to be paid on tobacco-pipe clays; by which name the Poole clays are designated in an Act of Parliament, obtained by Poole, in 1756. Mr. Rudley gives an extract from Hutching's *History of Dorsetshire*, published in 1774—for which he acknowledges himself indebted to Mr. William Joseph Pike, of Wareham—in which it is stated that these clays are the chief exports from the "Key of Wareham"; and from the edition of that work published in 1796, he quotes that "good tobacco pipe clay is dug round this town (Wareham) at Arne Hill, Heneger Hill, Norden, etc. It formerly sold at 50s. a ton, but now (1796) at 14s. or 15s. Nearly 10,000 tons are annually exported to London, Hull, Liverpool, Glasgow, etc., but the most considerable part to Liverpool (Runcorn), for the supply of the Staffordshire potteries, and to Selby for the use of the Leeds potteries. The principal pits are on Norden and Witch farms, the former belonging to William Moreton Pitt, Esq., and the latter to John Calcraft, Esq., and the clay taken from the same is in great repute with the Staffordshire and Yorkshire potteries from its peculiar excellence, and being the principal ingredient in the ware commonly called Staffordshire ware, so universally in use in this Kingdom, as well as in many parts of Europe." In 1874 the production of Poole clays was 79,205 tons, and of Teignmouth clays 59,789 tons. The production in 1882 will be given at the close of these papers. Bristow states that much of the Dorsetshire pipe clays, which are not of sufficiently good quality for use in the potteries, is converted into alum by treatment with sulphuric acid. In his paper on the white clays of the Lower Tertiaries already referred to, Mr. Maw gives the under-noted analyses of the clays of the Bovey Tracey lignite deposits, No. 1, being a china ball (or pipe) clay, and No. 2, a blue ball clay from Newton

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[1] *Report on the Geology of Cornwall, Devon, and West Somerset*, by Sir T. de la Beche, F.R.S., 8vo, 1839.

Abbot; he also gives, No. 3, an analysis of blue ball clay from Wareham.

	No. 1.	No. 2.	No. 3.
Silica	67·50	47·00	60·00
Alumina	29·00	48·00	34·00
Oxide of iron	1·00	1·50	2·50
Magnesia	1·50	2·00	—
Potash	—	—	2·00
Water and waste	1·00	1·50	1·50
	100·00	100·00	100·00

Mr. Rudley gives the undernoted as the relative composition of the ball clays of Devon and Dorset respectively, from analyses made in the Laboratory of the Museum of Practical Geology, by Mr. W. Weston, viz.:—

Bovey or Teignmouth Clay, a natural Kaolin from Bovey Heathfield, Devonshire.

Silica	52·06
Alumina	29·38
Potash	2·29
Lime	0·43
Magnesia	0·02
Protoxide of iron	2·37
Water, combined	10·27
,, hygroscopic	2·56
	99·38

Poole, or Blue Clay, from Wareham, Dorsetshire.

Silica	48·99
Alumina	32·11
Potash	3·31
Lime	0·43
Magnesia	0.22
Protoxide of iron	2·34
Water, combined	9·63
, hygroscopic	2·33
	99·36

Ansted[1] gives the following analysis as that of the best blue clay—such as occurs in the Wareham beds, viz.:—

Silica	46·38
Alumina	38·04
Iron oxide	1·04
Lime	1·20
Magnesia	trace
Water	13·57
	100·23

In the Island of Purbeck there are deposits of clay of such a variety of composition, that they may be found there suitable for every purpose, except those for which kaolin, or the best china clays, are required.

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[1] *Lectures on Practical Geology*, by Professor J. T. Ansted, M.A., F.R.S., London, 1865.

CHAPTER VII

ORIGIN AND OCCURRENCE OF KAOLIN OR CHINA CLAY

HAVING now given a brief account of those pottery clays, so called, chiefly used in the manufacture of earthenware, it may be interesting to refer shortly to a noticeable difference in at least the mode of occurrence, if not in the origin as well, of these clays from that of kaolin, or china clay proper.

The former may be called *natural* products in contradistinction to the latter, which are so far *artificial* that, with a few exceptions—which are sufficient to show, however, that the difference between them is more accidental than essential—they do not occur as deposits fit for use without certain processes of preparation, which are not necessary in the case of the former.

The pottery clays, whatever their origin, have been separated from the rocks from which they are derived by the disintegration of the latter by natural agencies, chemical and atmospheric, and except in such cases as those referred to by Mr. Maw, in which they are found in hollows of the chalk or limestone rocks, from which they have probably, as he believes, been derived, have afterwards by rains or streams been gradually washed down, during long periods of time, into lakes or estuaries, until they formed thick beds, such as those of Bovey Tracey, Wareham, Purbeck Island, and other localities.

In the transport, by the agency of running water, of the materials separated by the chemical and atmospheric action ferred to, from the rock masses they have been derived from, would naturally, according to the nature of the intervening ground and the length of transit from their higher source to their final deposit, be assorted into beds of varying composition —particles of undecomposed rock, grains of quartz, iron pyrites, and other impurities, being the heavier of these materials, would mostly be gradually left behind, *en route*, or deposited near the margin of the lakes or estuaries; while the finely-divided particles of clay, owing to their lighter specific gravity, would be carried beyond these, and ultimately deposited in the beds, of which they constitute the bulk, in a comparatively pure state. As the clays of the Bovey Tracey beds may probably have been carried, so far as they have been derived from the granites of Dartmoor, a distance of 10 to 12 miles, if not more, it is thus easy to account for their comparative purity. On the other hand, where any of these clays, or those of the Poole beds, have been derived from other rocks, such as chalk or clay slate, or perhaps in some cases from previously formed argillaceous sedimentary deposits, from a less distance, the freedom of those rocks or deposits from the other ingredients, associated in the granites with those constituting silicates of alumina, would as satisfactorily account for their purity.

Thus, whatever their origin, these pottery clays are found deposited in thick beds, washed and freed by Nature's hand from all such extraneous ingredients as would otherwise have prevented their employment without such preparatory processes as are necessary to produce kaolin in a state fit for potting and other manufacturing purposes.

The mode of raising the Teignmouth and Poole clays is an extremely simple one. It is thus described by De la Beche[1] :— The gravel or other surface covering, or "head," as it is called, being removed, large rectangular pits are sunk, the sides of which are supported by timbers. As the pits are sunk stages are erected, and the workmen who cut out the clay in cubical lumps, weighing from about 30 to 35 lb. each, fling them up by means of a pointed staff, from stage to stage, according to the depth, after which the lumps are carried to the clay cellars or sheds, whence they are forwarded, when sufficiently dried, for shipment to the potteries or elsewhere.

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[1] *Report on the Geology of Cornwall, Devon, and West Somerset*, by Sir H. T. De la Beche, F.R.S., 1839.

As might naturally be expected, these beds of clay, occurring thus in a state ready for use in the manufacture of pottery, were certain to be utilised, as they were, at an earlier period than that in which, owing to the increased importation of Chinese porcelain—first introduced into Europe as an article of commerce by the Portuguese, about the year 1520—(although there are notices of Eastern porcelain having found its way there twenty years or more previous to that date) an improved taste, and the consequent desire to imitate and rival the Chinese porcelain, led to numerous attempts to improve European wares, and for that purpose to find superior clays to the pottery clays then in general use. Although, however, it is said that a soft paste was made in Florence as early as 1580, it was not till 1709 that Böttcher was successful in finding china clay and in making white porcelain in Saxony. In 1710 he was appointed by Augustus II., Elector of Saxony, director of the Meissen factory, and five years later he succeeded in making excellent true hard porcelain there. That factory is still in operation, and producing the fine porcelain known as Dresden china. What clays Böttcher first used in Saxony is not known, although it is probable it was those found at Seilitz, near Meissen; but he finally employed the china clay of Aue, near Schneeberg, in the Erzgeberge, one of the best-known localities for it in Europe; where the finest porcelain clay is obtained from beds of decomposed gneiss—a metamorphosed granitoid rock, composed like granite of felspar, quartz, and mica. In gneiss the felspar often, if not generally, occurs in a soft state, and destitute of potash, or nearly so, and by decomposition thus readily produces kaolin. This kaolin was long known as Schnorr's white earth, owing, it is said, to its discovery by John Schnorr, an ironmaster, who, riding near Aue, observed a soft white earth adhering strongly to his horse's feet. This was subsequently used and sold largely as hair-powder, as a substitute for wheat-flower, and some of it coming into Böttcher's hands, he was led, from finding it heavier than the ordinary powder, to experiment with it, which resulted in his discovering its identity, as was then supposed, with the Chinese kaolin—the substance he had long sought for the manufacture of his porcelain.

This porcelain earth of Aue, according to a report by Mr. Oelschlagel, referred to by the late John Hawkins, F.R.S.,[1] occurs in a cone-shaped, eruptive, granitoid mass, covered by micaceous slate, in two beds, separated by a bed of granite, the whole of which is in a very decomposed state; the felspar being converted into kaolin, which constitutes from a fourth to a fifth of the mass, mixed with quartz, undecomposed orthoclase felspar, mica, oxide of iron, and pinite; the purest being found at the top, and the fineness and friableness of it diminishing in depth, until it passes, through all degrees of induration, into a firm crystallisation of felspar, while the quartz and mica occur in masses easily separable by the hand.

Next to Aue, the principal spot in Saxony where the porcelain earth occurs is at the village of Seilitz, above mentioned, where it is found 20 feet thick, with a covering of clay with shells, and resting on a bottom rock of porphyry. It is mixed with quartz and particles of greyish clay; and lumps of pure kaolin of the size of a man's fist occur in the mass. This porcelain earth is more free of oxide of iron than that of Aue, but it shrinks more in the kiln, and produces a less durable porcelain. Mr. Oelschlagel's opinion of this porcelain earth is, that it has been formed from the decomposition of porphyry. He probably means a porphyritic granite, such as that of Cornwall and Devon, containing large prismatic crystals of felspar, by the decomposition of which the clay would be produced.

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[1] In a paper in *The Transactions of the Geological Society of Cornwall*, vol. vi. p. 32.

In the Principality of Passau, in Austria, Gehlen states that kaolin occurs at Kellberg, in a district of gneiss and granite, near the surface, and in a state of great, although much-varied, decomposition, the felspar, in some portions, being found in every stage of disintegration, in others, entire and unaltered. The chief deposits of the kaolin are formed, he says, by stratified masses of decomposed felspar, alternating with a very decomposed gneiss; and while the felspar, on the one hand, occurs in every possible stage of decomposition, the kaolin, on the other, exhibits various degrees of fineness, or of pulverisation, some of it being so pure and impalpable as to be wholly suspended in running water, while others retain a sort of grittiness to the touch, seemingly occasioned by an imperfect or disturbed crystallisation. From the beds at Kellberg, near Passau, the Royal Factories of Vienna and Munich are supplied with kaolin.

In 1750 the manufacture of porcelain was commenced at Berlin, and in 1763 Frederick II. bought the works there, and converted them into the Berlin Royal Factory. The Berlin porcelain is made from kaolin found at Gomritz, below Halle, in the district of Magdeburg, and at Gothenburg and Giera, in Lower Silesia.

Among the European Royal Porcelain Manufactories, that of Sèvres holds the first rank. It was purchased by Louis XV., in 1759, who appointed Boileau director, and, besides perfecting the works, the latter occupied himself in the endeavour to make hard paste, and made several attempts, by purchase and otherwise, to secure the secret of the process claimed to be in the possession of the Hannongs, of Strasburg, and others, but unsuccessfully. As Jacquemart has said,[1] "The invention of real hard pottery is less within the domain of ceramic industry than of geology; there—no efforts of imagination, of creation properly so called—the felspathic rock must be had; the rest comes from one's self. Porcelain produced herself naturally the day when people, strangers to science, had laid their hand upon the sought-for clay." "And it was by chance at last," says the same author,[2] "that France acquired the coveted material." "One Madame Darnet, wife of a surgeon of St. Yrieix la Perche, about 10 leagues from Limoges, found in a ravine a white, unctuous earth, which appeared to her fit for washing linen. She showed it to her husband, who, more versed in the questions of the moment, suspected that this might be the clay they sought for. He ran to an apothecary at Bordeaux, named Villaris, who recognised it to be kaolin. Then took up specimens, which were transmitted to the chemist Macquer, of Sèvres. He went to St. Yrieix, in August 1765, and, after repeated experiments, was able to read to the Academy, in June, 1769, a complete memoir upon French hard porcelain, and to exhibit perfect types." The composition of the St. Yrieix kaolin, which is that used at the Sèvres factory, is—silica, 48·00; alumina, 37·00; alkalies, 2·05. It occurs there very abundantly in decomposed granite, resembling that of Cornwall. It is generally white, sometimes, from the presence of iron, of a yellowish tinge, and has very little mica. Like most of the kaolins, it is meagre to the touch, and contains a good deal of free silica, in the form of quartz grains. It makes a very transparent porcelain, and since its employment at Sèvres, the fame of the St. Cloud factory has been much enhanced, especially under the able scientific directorship of the late M. Alexandre Brogniart.

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[1] *History of the Ceramic Art*, by Albert Jacquemart, 2nd edition, 1877, p. 573.

[2] *Ibid*, p. 578.

From the dates above given, it will appear that the discovery of china clay in this country was almost contemporaneous with its discovery in France, and not long after its discovery in the comparatively few localities in Saxony and other parts of the continent, where, as yet, it has been found. The instances, and dates of those given, may suffice, as these chapters have to do—not with the history of European, or even English earthenware and porcelain, but—solely with the potting materials themselves.

In 1745 an adventurer brought back with him to London from Virginia some kaolin, which, owing to its rarity, sold at that time for 13 guineas a ton. William Cookworthy, a Plymouth quaker and chemist, is said to have had his attention directed to this material by the person just referred to, and as he had started a pottery at Plymouth in 1733, he, it may be presumed, was much interested in it; and having a great aptitude and liking for geological research, he doubtless, during his journeyings through Cornwall, had been long searching for a superior clay to those of the Teignmouth and Poole beds, which he probably had been using in the above works. The existence of the Cornish clay and stone may have been known to him for some time ere he could favourably for his own interest make it publicly known. It has not been clearly ascertained when he first discovered them, but from a short account of his life published by his grandson,[1] it was about the year 1755, and if so, it was the first discovery of the china stone in Europe. It may be presumed that the stone was discovered by him first, and that by further investigation and experiment by levigation of the clay so often found associated with the china stone *in situ*, he found it to be kaolin. From his grandson's account he appears first to have found both the stone and clay at Tregonning Hill, near Breage, then in the parish of St. Stephen's, and afterwards in the domain of Boconnoc, the family seat of Thomas Pitt, nephew of the Earl of Chatham, and afterwards Lord Camelford. In 1768 Cookworthy, in company with the latter and others, secured by patent the exclusive use of the Cornish china clay and stone, and with these materials, along probably with the clays of Devon or Dorset, carried on the manufacture of porcelain for some years at the Plymouth pottery, which undoubtedly was the one at which "hard" or true porcelain was first made in England. Borlase, in his *Natural History of Cornwall* (1758), mentions white clays at Tregonning Hill, but without being aware of their nature evidently. He states that Cookworthy had made experiments on the Breage china stone, and that it had been found useful for the manufacture of porcelain. Pryce, in his *Mineralogia Cornubiensis*, published in 1778, states "that artificial kaolin (china clay) was then prepared in the parishes of Breage and St. Stephen's by repeated washing with clear water, and afterwards packed in casks and sent off, and that Mr. Cookworthy, by his late improvements at his porcelain manufactory, then established at Bristol (having been removed thither from Plymouth), was likely to produce ware which should rival the best Asiatic china."

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[1] *Memorials of William Cookworthy*, by his Grandson, with an ndix, London, 1854. Also another Appendix published in 1872.

CHAPTER VIII

CORNISH CHINA CLAY—COMPOSITION AND ANALYSES

PORCELAIN clay is the purest form of hydrated silicate of alumina, and is a substance of comparatively rare occurrence in a natural condition. Even the material from which it is generally artificially produced has as yet been found in Europe but in few localities; and in England only in the granite rocks of Dartmoor in Devonshire, and in those of Cornwall. From the fact of the great bulk of its production in England being from the latter county, it is often called Cornish clay; but the name by which it is best known, and which is that generally used by potters, is that of china clay. Outsiders—scientists and others—usually call it kaolin, but, if by that is meant that it is really identical in composition with the Chinese kaolin, it is questionable if that name be not a misnomer when used for Cornish clay. Kaolin, however, has been so long in general use, and is so short and convenient, that it will probably continue to be used for Cornish clay, so long at least as people are satisfied to use such names as shell-fish for molluscs, which are not fish at all; or blacklead for graphite, of which pencils and crucibles are made, and which has not an atom of lead in its composition. The Chinese porcelain clay will be referred to at length. In the meantime, however, it may be suggested that "clarclazin" would be a more correct scientific name for Cornish clay than that of the Chinese term kaolin, as being derived from the ther decomposition of the granitic rock, for which the of "clarclazite" has been proposed by Mr. Collins, in his valuable monograph of *The Hensbarrow Granite District*.[1]

Mr. Collins' monograph treats so fully of china clay and its production, that it ought to be in the hands of every potter who takes any interest whatever in the materials which he employs or works with.

There are many persons, however, in every trade who do not interest themselves in the natural history of the materials with which they work; and while space cannot be afforded in its pages for such full details as are requisite for the completeness of monographs of the various materials used by the trade, its proprietors have been encouraged to provide such popular accounts of these as may be likely to awaken a scientific interest in them, amongst those of its readers who may not hitherto have thought of them in this way.

Although, as will be shown hereafter, there are other rocks than granite from which china clay might be, and probably before long will be, produced, its production as yet has been confined in England to the material known in Cornwall as soft "growan," which is a more or less decomposed granite. It is by the decomposition of the felspar of the granite, which is its base, and constitutes never less than a third and generally at least one-half of its bulk, and sometimes even more, that its disintegration occurs. It has been shown[2] that in the largest granitic mass in the United Kingdom, that, namely, which runs south of Dublin, for a length of 70 miles or so, the granite contains 52·94 per cent. of felspar, while the composition of the granite of Slievenaglogh (Mourne Mountains) shows a still larger proportion of felspar, it being composed of—

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[1] *The Hensbarrow Granite District*, by J. H. Collins, F.G.S. Lake & Lake, Truro, 1878.

[2] In a paper on the "Lower Palæozoic Rocks of the South-East of Ireland," by Professor Haughton and J. Beete Jukes, *Trans. R. I. Academy*, vol. xxiii.

Quartz	20·70
Felspar	66·37
Mica	12·76
	99·83

and the felspar of the Hensbarrow granite forms two-thirds, or 66·66, of the mass, according to Dr. Berger.[1] Professor Haughton[2] holds that the granites of Cornwall were, in their primitive condition, of igneous, and not like many other granites, of aqueous origin, but they are of a much looser texture than most granites, and therefore more readily disintegrated by atmospheric influences. Mr. Sorby, F.G.S., who is so famous for his microscopical examinations of rocks, concludes that the granites of the Scottish Highlands indicate a pressure when being consolidated of 26,000 feet more than in the case of the granites of Cornwall.[3] This may help to account for the fact of their being, in some localities, so generally reduced
ition of growan, and of the absence of a similar
t other granitic districts.

f the Cornish granites is generally that known
potash felspar; and it is mainly from the
f this that the china clay is produced. Its
be given as follows, viz.:—

	65·50
	16·80
	17·70
	100·00

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[1] eological Transactions, O.S., vol. i.

[2] ual of Geology, by the Rev. Samuel Haughton, M.D., F.R.S., p. 41.

[3] ations on Granite," Geological Society's Journal, vol. xiv.

This shows it to be rich in potash, and if this alkali was retained in the china clay, it would become fusible and unsuitable for the manufacture of porcelain, the refractoriness of the clay being entirely due to the absence of alkalies or alkaline earths. Its composition may be given as—

Silica	46·40
Alumina	39·70
Water	13·90
	100·00

Now in comparing these two substances, it will be at once seen, that of the silica of the felspar 19·10 has disappeared, and that, while the whole of the potash, 17·70, has also gone, the alumina has been increased by 22·90, while the net loss of 13·90 has been replaced by water, thus—

Silica	−19·10	+	Alumina	22·90
Potash	−17·70		Water	13·90
	36·80	=		36·80

Some geologists maintain that china clay results from the decomposition of the white soda felspar, albite, an ingredient of some granites. Professor Ansted, for instance, says: "The kind of granite which most readily decomposes is that whose felspar is of the variety called albite, a pearly white variety in which soda replaces the potash of ordinary felspar."[1] Its composition may be given as—

Silica	69·30
Alumina	19·10
Soda	11·60
	100·00

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[1] *Lectures on Practical Geology*, by Professor D. T. Ansted, M.A., F.R.S. Hardwicke, 1865.

And comparing this with the foregoing formula of china clay, it will be noticed that in this case 22·90 of the silica has disappeared, and the whole of the soda, 11·60 = a loss of 34·50, while there is an increase in the alumina of 20·60, and the addition of 13·90 of water, thus showing—

Silica . .	−22·90	+	Alumina . . .	20·60
Soda . .	−11·60		Water. . . .	13·90
	34·50	=		34·50

As in the other case, the alkali soda, if retained, would also destroy the refractory character of the clay.

Now the question will at once present itself to anyone looking at these results of the decomposition of the felspars—what has taken place by which the plastic refractory china clay is produced from a highly fusible, anhydrous, and unplastic material?

In an interesting article on Cornish china clay by Mr. James Quick,[1] it is affirmed that "No generally accepted conclusion has yet been arrived at as to the direct causes of the formation of kaolin. Indeed," he says, "no very great amount of scientific inquiry has yet been brought to bear upon the subject. *Watt's Dictionary of Chemistry*, vol i., says: 'Kaolin may be supposed to be formed from orthoclase or $K_2OAl_4O_3,6SiO_2$, by the abstraction of the whole of the potash and two-thirds of the silica, and the addition of two atoms of water'; but offers no suggestion as to how this may by nature be brought about."

On this point, as may be supposed, opinions of chemists and geologists differ; but briefly it may be taken for granted that atmospheric agencies are the chief agents in producing the growan from which the china clay is separated by the action f water. One such agency is undoubtedly that of carbonated r; rain water absorbs about twice its volume of carbonic acid from the atmosphere, and in acting upon the felspar it combines with the alkalies, and forms soluble carbonates of potash and of soda, and these are carried off by the rainfall or streams from the higher regions where the granites are generally found, and conveyed to the valleys and low-lying grounds, where they supply the necessary aliment to the soil, for the nourishment of grain and other crops. The silica is set free—a certain part of it combines with the alumina and water to form the hydrous silicate of alumina, clay; or part of it remains uncombined, and is carried off in solution or otherwise.

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[1] *Quarterly Journal of Science* for October 1877.

Mr. Collins quotes Von Buch's observation of the constant occurrence of fluorine minerals with china clay, and his opinion that the clay in the neighbourhood of Halle owed its origin to the action of hydro-fluoric acid upon the felspars; and also that of Daubrée, who, writing in 1841 of that in the neighbourhood of St. Austell, stated that it must have had a very similar origin (*Monograph*, pp. 34 and 35).

He further states that the clay "of the Hensbarrow granite," and, in his belief, "that of all other parts of Cornwall and Devon, is accompanied invariably by lepidolite" (which contains 4·81 of hydro-fluoric acid), "and almost invariably by tourmaline" (which contains 2·50 of fluorine), "so that fluorine in considerable proportions is never absent," and, indeed, "is everywhere present in the china clay districts." He describes its action on the felspar, which he believes "would readily give up its alkali (and part of its silica also) to the fluorine or decomposable fluorides, and be thereby reduced to the state of silicate of alumina—part of the alkaline fluoride passing away in solution, the rest being deposited with the silica as lepidolite among the particles of kaolin."

By which of these chemical agencies the china clay may have been or is produced it may be difficult to decide with certainty. Probably both have had a large share in the decomposition of the granite that has taken place in Cornwall on so extensive a scale, and both are probably still in constant operation in the production of "growan." Mr. Collins states that a high temperature is not essential to the action of fluorine in the decomposition of felspar, for, he says (p. 36), "I have kaolinised orthoclase, and also the felspar of the Cheesewring granite by means of hydro-fluoric acid at ordinary temperatures, without apparently affecting the other ingredients of the granite."

In the introduction to the *Catalogue of Specimens in the Museum of Practical Geology*, it is stated (p. 3) that "the potash, soda, lime, or oxide of iron that may be present in the original felspar (from which the china clay is derived) is removed to a great extent in the form of soluble carbonates or bicarbonates by the action of water holding carbonic acid gas (carbon dioxide) in solution"; and referring to the felspars which are important as constituents of rocks, "the chief species of which are orthoclase, albite, oligoclase, labradorite, and anorthite," it is stated, that while all these are "liable to decomposition, under certain conditions, and may thus yield clay-forming materials, it is observable that those species
are poorest in silica, and which contain much lime,
readily decomposable than those which are richer in
in less lime, but more potash and soda. Thus,
rred that labradorite and anorthite are more
tion than are the more highly silicated felspars—
e, and oligoclase. It is, however, the three
ve yielded the base of all our ordinary clays,
again, orthoclase may, perhaps, be regarded as
which has done so most abundantly." The
nvolved in the above quotation is one requiring
r elucidation, if the presence and action of fluorine may
ount for it,

CHAPTER IX

CORNISH CHINA CLAY

IN the last chapter, reference was made to the Chinese kaolin, which it was proposed to discuss more fully in this one, but as we had not finished what remained to be said about Cornish clay, the subject of Chinese kaolin must be postponed for the present.

Cornish porcelain or china clay is mineralogically described by Dana and others, as occurring massive, or disseminated, in rhombic, rhomboidal, or hexagonal scales or plates, sometimes in fan-shaped aggregations, usually constituting a clay-like amorphous mass, composed of small particles, which possess only a slight degree of coherence (and, therefore, somewhat deficient in plasticity); compact, friable, or mealy. Colours generally various shades of white or greyish-white, but sometimes—from the presence of iron or other impurities—yellowish, brownish, bluish, or reddish. Opaque, sectile; adheres slightly to tongue, soft and meagre to the touch when dry, unctuous and plastic when wet. Lustre, pearly to dull earthy. Insoluble in acids, but decomposed by hot sulphuric acid, which dissolves the alumina and leaves the silica. Gives a blue colour with cobalt solution, H., 1·0—2·25; sp. gr., 2·21—2·63; B.B., infusible.

Composition—Hydrous silicate of alumina, viz. silica, 46·40; alumina, 39·70; water, 13·90, as already given. Ordinary china clay under the microscope, if not without, is seen to be largely made up of minute six-sided scales or plates of pearly lustre, translucent, flexible, inelastic, usually unctuous and plastic.

China clays possess very characteristic properties. They are of a loose earthy texture, and light, friable in the hand, meagre to the touch, and do not readily form a plastic paste with water. Their composition is different from different localities, the limits being very wide. Professor Ansted gives[1] the following analysis as that of their average composition, viz.:—

Silica	44·60
Alumina	44·30
Oxide of iron	·20
Lime and magnesia	1·60
Water	8·74
Loss	·56
	100·00

But samples sometimes, he says, contain as much as 10 or 12 per cent. of free silica, either as fine or coarse sand, mixed with the clay.

In the above analysis he overstates, however, the percentage of alumina, which rarely reaches or exceeds 40 per cent.; and the undernoted ones which he gives as that of the finest china clay, is much nearer the mark, viz.:—

Silica	46·32
Alumina	39·74
Oxide of iron	·27
Lime	·36
Magnesia	·44
Water	12·67
Loss	·20
	100·00

The Cornish and Devon porcelain clays generally contain ne spangles of white mica and finely comminuted quartz, h indicate their origin from granites. They are nearly all

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ns *of Geology to the Arts and Manufactures*, by Professor , F.R.S., p. 116.

artificially derived from the decomposition (as it is generally believed) of the felspar in the schorlaceous and other granites, which are so abundant in the St. Austell and other districts of Cornwall, and of Dartmoor in Devonshire. Of these, pegmatite, a binary granite, is composed of quartz or felspar, but often containing small flakes of silvery white mica; and protogene, a talcose granite (like that of the Alps, which however has in some places a dull mica, or chloritic mineral instead of talc) is composed of quartz, felspar, and talc. The latter derives its name from an erroneous idea that it is the first formed, or oldest of the granites; whereas De la Beche has shown that the Cornish granites belong, like those of the Alps, to the secondary formations, and are indeed newer than the carboniferous.

The Cornish china clay is chiefly derived from the decomposition of protogene—a granite which contains talc as an ingredient, and is peculiarly liable to undergo extensive disintegration. When schorl is present, as it often is in veins and cavities of these granites, it has, of course, to be carefully separated, along with the other impurities, in preparing the clay.

Dr. Boase states[1] that "protogene granite is, of all others, the most extensively disintegrated, in which state it is provincially called china clay. It abounds in St. Stephen's and the adjoining parishes, and in Tregonning Hill, near Breage, and affords an interesting subject for geological inquiry. The formation of this substance (china clay) is generally attributed to decomposition. It must, however, be acknowledged that, if such be its origin, the elements have, in this instance, greatly transcended their usual operations."

The proportions of the constituents of granite vary indefinitely—with this limitation, that the felspar is always, with quartz, an essential ingredient, forming a large proportion of the whole, as noticed in Chapter VIII., the mica, however, sometimes being barely perceptible—and owing both to that, and also to the varying state of decomposition in which it occurs in the various localities where it is worked for the clay, the latter also varies much in composition, as will be apparent from the various analyses which will be given hereafter.

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[1] "On the Geology of Cornwall," by Henry S. Boase, M.D., *Trans. Royal Geo. Society of Cornwall*, vol. iv. p. 379.

In a communication, with which the writer was lately favoured, from Robt. W. Armstrong, Esq., of Belleek, Fermanagh, he gives the following as examples of the varying composition of the Cornish granites, from which the porcelain clays are derived, viz.:—

Silica	70·0	to	74·0
Alumina	16·0	,,	18·0
Potash	8·0	,,	5·0
Soda	0·0	,,	3·0
Lime	1·0	,,	1·0
Magnesia	0·0	,,	0·5
Water	4·0	,,	0·0
	99·0		101·5

Mr. Collins states,[1] that "in each of the granite masses which rise like islands in the sea of clay slate forming the western extremity of England, some portions have their felspar so decomposed as to be converted into china clay. Other portions are less decomposed, and are of somewhat different composition, and these supply the china stone. These decomposed portions are always associated with veins of black tourmaline (schorl) and other minerals containing fluorine"; and he states that, in his opinion, the decomposition of the felspar "has certainly been effected by fluorine and other substances coming up from below, and not by carbonic acid and water acting from above."

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[1] "On the China Clay and China Stone of Devon and Cornwall," by J. H. Collins, F.G.S., *Journal of the Society of Arts*, vol. xxiv. p. 566.

He states also that "the natural china-clay rock, being a decomposed granite, consists of kaolin, irregular crystals of quartz, and flakes of mica, with sometimes a little schorl and undecomposed felspar." In the discussion which followed the reading of his paper, he further stated that the "bulk of china clay came from granite which had been decomposed *in situ*, in his opinion, because they could often see its gradual passage from china-clay rock (clarclazite), and large porphyritic crystals of felspar could often be seen changed into kaolin without losing their form."

In opposition, however, to the theory of decomposition of the felspar, whether from above or below, Mr. John Hawkins, F.R.S., maintained the opinion that the soft growan, from which the china clay is obtained, is in its original condition; the lapidifying power having been arrested, or not as yet having extended so far upwards; and in corroboration of this opinion he states[1] that at the Beam mine, in the parish of Roche, Cornwall, the works are "actually sunk alternately through hard and soft growan," which fact will scarcely sustain the inference he draws from it, as it may equally well be adduced as proof of incomplete decomposition; but he further refers to various sections of that mine, and states that "from these it appears that the hard growan occurs nowhere in the upper levels of the mine, and that it occupies a small portion only of the lower; that it alternates with the soft growan; that it is not always found at corresponding levels, and that it terminates abruptly in a line which corresponds with the underlie of these veins."

Mr. Hawkins, in support of his theory, refers to several clay pits on Hensbarrow, and on the hills of St. Mewan,

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[1] "Some Account of the Soft Growan at the Beam Mine, in the Parish of Roche, and at Carclaze Mine in the Parish of St. Austell," by John Hawkins, Esq., F.R.S., *Trans. Roy. Geo. Soc. of Cornwall*, vol. iv. p. 475.

but states that "the most striking evidence of the aboriginal existence of the soft growan is perhaps that which is displayed at the celebrated excavation at Carclaze, in the parish of St. Austell, where its removal is effected by a stream of water—the growan being in such a condition there that it may be called a clay-pit. The growan exhibits no marks of sedimentary or of stratified divisions," and in the "arrangement or distribution of its constituent parts, it differs in no respect from the hard growan. In short, there are no traces of any change or disturbance, and every part of the mass seems to be in the same state of induration; the lodes, too, which traverse it bear, like the same lodes in the Beam mine, no marks of either dislocation or displacement, and, moreover, so compact is the mass of this soft rock, that I conceive it hardly possible for any rain to penetrate through it, without which it is difficult to support the hypothesis of decomposition." He further quotes from Captain Samuel Robins, who states: "There is no reason whatever to believe that any water whatever can filter through the soft growan. We have sunk
fathoms through it without meeting with any
y occurs when we meet with a lode or a cross
it not for these we should find none. The
an cannot be called dry, neither is it moist;
are much in the same state as it is near the
damp." However these facts may appear to
general opinion of sub-aërial decomposition,
Mr. Collins' theory of decomposition, by the
e and other substances coming from below.
in the same paper as that above quoted, p. 380)
the gradual diminution in the cohesion of the
m the solid rock upwards will, of course, support
pinion of either party; but that the solid state of the
l the disintegrated state of the other, is not the only
; there is a chemical, as well as a mechanical, distinc-

tion; for the solid felspar contains an alkali which analysis has not detected in porcelain clay, and it therefore follows, since an alkali is not present in the perfect china clay as a constituent part chemically combined, that this substance, on account of its great solubility in water, cannot exist in a free state in the mass of china clay (soft growan), which, in its native bed, is always wet, for by the constant percolation of water it would be as effectually removed (naturally) as in the process itself, by which the porcelain clay is prepared. It may also be observed, that the stained parts, which the workmen reject under the name of 'weed,' are of a yellowish or red colour, indicating that the iron contained in the schorl has passed into a higher state of oxidation"; and as those beds of soft growan are generally bounded by solid granite, and are often traversed by large masses and veins of quartz containing schorl, Dr. Boase quotes these circumstances as another argument against Mr. Hawkins' opinion, for he says: "It is difficult to conceive why the power (lapidifying), whatever it might have been, should have acted so partially in its operations, as to have consolidated one part of the mass, and to have left the other in a loose, friable state. Again, the partially changed granite, called china stone, will in time entirely lose its cohesion"—an evidence of sub-aërial decomposition in the writer's opinion—"as may be seen in the numerous masses around the quarries, which, although retaining their form, immediately crumble into pieces on attempting to remove them. And, lastly, the analogy of other rocks affords, perhaps, the best proof that china clay is a decomposed granite."

It will be noticed from the above, that Mr. Hawkins and Dr. Boase—both of whom are intimately acquainted with, and have written upon, the geology of Cornwall—are at direct issue, not merely on a theoretical question, but on a matter of fact. Mr. Hawkins, backed by the experience of Captain Robins, stating that the soft growan is only in a damp state normally, and that water cannot percolate through it. Dr. Boase, on the other hand, stating that in its native bed it is always wet, and that the absence of the alkali of the felspar in the china clay is due to its great solubility, and to its being effectually removed by the constant percolation of water through the growan.

There are not a few, as yet, unsolved problems connected with this subject, and one object the writer has in view is to direct further attention to it, with the view of stimulating inquiry and discussion. Mr. Carne states[1] that "the china-stone of St. Stephen's might perhaps be mentioned as another variety of granite; but," in his opinion, "it owes most of its difference from ordinary granite to decomposition." The opinion of Mr. Carne, which prevails very generally, is, Dr. Boase remarks (p. 381), "very surprising, for this property of undergoing such extensive decay is alone sufficient to indicate that it (the St. Stephen's granite) is a rock *sui generis*; besides, it is peculiar in composition, containing talc instead of mica; which circumstance," he says, "may afford a clue to the explanation. Not that the talc itself can be supposed to exert any direct action on the felspar; but, in consequence of its having been formed, instead of mica, in the original crystallisation of this rock, the felspar may have experienced some modification in the proportion of its constituent parts, whereby it acquired the property now under consideration."

This presence of talc — which is a mineral, containing as much as 32·92 of magnesia — in numerous greenish-yellow glossy scales in the St. Stephen's granite, however it may have affected the constitution of the felspar, but seldom occurs in the china clay, for in nearly all the analyses of it there are but traces, or very small quantities of it, to be found. The magnesia, like lime, being an alkaline earth, is carried off in solution like the alkalies. It would be an advantage for the refractory quality of the Cornish clay did it contain more, as is generally the case with the Chinese kaolins.

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[1] "On the Granite of the Western Part of Cornwall," *Transactions ographical Society of Cornwall*, vol. iii. p. 212.

The essential and striking difference in composition between china clay and the felspathic growan (Mr. Collins' clarclazite) from which it is produced, and which was shown in the last chapter, has led to the opinion being held by some mineralogists and chemists, and specially by Professor Fuchs, of Landshut, that ordinary felspar is not the source of china clay. Professor Fuchs, in a memoir on the origin of the porcelain earth of Passau, printed in the *Transactions of the Royal Academy of Munich*, and quoted by Mr. John Hawkins,[1] states that he visited the pits where the best earth was dug, and directed his attention particularly to the felspar, said by Gehlen to form by its decomposition the porcelain earth, and found that the mineral so named was essentially different in its form of crystallisation and characters from ordinary felspar. He described the rock in which the crystals of this mineral substance lie, as "a fine-grained or aggregated felspar, of a greyish colour. Few of the crystals were entire, but nearly all of them, more or less decomposed, and the friable mineral had all the properties of porcelain earth." His analysis of them gave:—

Silica	49·30
Alumina	27·90
Lime	14·42
Soda	5·46
Water	0·90
	97·98

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[1] "Some Account of the Porcelain Earth found in the Kingdom of Saxony and the Principality of Passau, collected from German publications, and sent to the Royal Geographical Society of Cornwall," *Transactions*, vol. vi. p. 32.

Professor Fuchs, from this result, and the form of its crystallisation, as well as its other characters, considered this mineral as a new species, distinct from any known species of felspar, and named it porcelain-spar. His analysis of the earth formed, as he believed, from the decomposition of this mineral, in its pure and natural state, he gives as :—

Silica	46·70
Alumina	31·80
Lime	0·46
Oxide of iron	0·82
Felspar[1]	3·00
Water	17·14
	99·92

and he seemed to regard the porcelain earth of Aue, in Saxony (which, by the bye, appears now to be exhausted), as having been precisely similar.

Mr. Hawkins says, that the principal arguments upon which Professor Fuchs vests his opposition to the opinion, held by most mineralogists, of porcelain clay being produced by the decomposition of felspar, are—"The total absence of all traces of potash in the waters which flow from the decomposed masses of granite, and the occurrence of the purest porcelain clay enclosed in felspar, and, *vice versâ*, of felspar in porcelain clay." Professor Fuchs was by no means disposed to adopt the opinion, held and advocated by Mr. Hawkins, of this earth (porcelain clay) being an original product of Nature, but, on the contrary, held it to originate in the decomposition of porcelain-spar, the mineral he claims to have discovered. As to the process of decomposition, he thought it might be satisfactorily explained, "for in such a complicated mixture as this is, the presence of soda and the calcareous earth (lime) must have disposed the porcelain-spar to yield to the active agency of water and the carbonic acid, by which all the soda and the lime have been carried off in a state of solution, together with a portion of the silica."

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[1] Undecomposed and accidentally mixed.

Mr. Hawkins naturally points out that Professor Fuchs, by this statement, places himself in a dilemma, there being no traces to be found of the soda and lime in the water flowing from the decomposed porcelain-spar any more than of the potash from decomposed felspar, and Mr. Hawkins proceeds to controvert Professor Fuchs' conclusions. Sufficient space, however, is not available in these pages to do more than indicate the various theories or opinions held on the subject, and the writer must refer those interested in it to Mr. Hawkins' paper itself.

In that paper he proceeds to refer to a report drawn up by Mr. Gehlen, first published in the *Transactions* of the Royal Academy of Munich, and afterwards reprinted in the second volume of Von Moll's *Annals of Mining and Metallurgy*, upon the porcelain earth found in the principality of Passau, which supplies the royal manufactories of Vienna and Munich. In that report Mr. Gehlen says: "It remains for me to speak of the natural history of this porcelain earth. I have already quoted the opinion, which is universally adopted, of its originating in the decomposition of the felspar, and noticed its occurrence in a country of primitive formation, as well as the circumstance of its being found in its original position. This opinion of the origin of the earth is corroborated, in fact, by all the circumstances under which it occurs, both at Passau, and at Aue, in Saxony, where the beds of porcelain earth lie in a rock of granite, which, by the decomposition of the felspar, is in a state of perfect disintegration. The various degrees, too, of decomposition through which the felspar passes, in which, with the loss of all its other characters, it retains those of its original structure, seem to confirm this hypothesis. On the other hand, if we contemplate the very great difference which is found between the chemical composition of the felspar and that of the earth (china clay), we must feel inclined to the belief that they can have no common origin, and that each is aboriginal. According to the recent analyses of the best chemists, the felspar contains a very great proportion of silica, as well as a considerable quantity of potash, while the porcelain earth is found to contain not a trace of potash, and a much smaller proportion of silica." He might have added, "and a much larger proportion of alumina." "How then," he proceeds to ask, "can so considerable a difference as this is in the composition of these two substances have arisen from a process of decomposition? If we suppose this process to have set free the potash, which was afterwards carried off by water, yet it is but reasonable to suppose that the proportions of the other constituent parts would have remained unaltered. This difficulty cannot be removed by the supposition that the potash may have carried off a portion of the silica in a state of solution, and thus have increased the relative proportion of the alumina; for there are many chemical facts which oppose this conjecture, and it must be abandoned as untenable."

Mr. Gehlen concludes without advancing any fixed opinion upon this very interesting question, "nor," adds Mr. Hawkins, "can I find among the voluminous writings of the German geologists any serious attempt made to settle it. The hypothesis of the secondary origin of porcelain-earth seems," he says, "to have been generally adopted on the Continent." Mr. Hawkins, however, apparently holds to his own opinion of the soft growan, from which it is obtained in Cornwall, being not a product of decomposition, but an original formation, not perfectly lapidified.

The writer cannot presume to attempt to solve the problem, but he may remark, as a contribution towards it, that the question of time does not seem to have been sufficiently taken
account by those who have speculated upon it. Mr.
his monograph previously quoted, says (p. 6) that

"China clay, in its natural state, is simply a granite composed of white or pale smoky quartz, white mica, sometimes a little greenish-yellow gilbertite, and white felspar, in which the latter is partly or completely metamorphosed into kaolin," and he states that "this modification of granite occurs in areas of irregular form, and extending to an unknown depth." It has thus been apparently completely decomposed *in situ*, and to some considerable depth, and thereby reduced to such a condition that—if Mr. Hawkins' statements quoted above can be relied on—it has become, like the ordinary and more plastic clays, impervious to the percolation of water, and in consequence the process of decomposition being so far completed, at all events so far as surface deposits are concerned, little or no evidence can be found of potash being now carried off in solution, as in ages past when the process of decomposition was in active operation. When it was so, the action would be continuous, and the alkalies and alkaline earths, and portions of the silica being continuously carried off in solution, would leave an ever-increasing percentage of alumina to combine with the remaining silica—these two substances possessing great affinity for each other—to form with water the hydrous silicate of alumina or china clay, that being a very different process, however, from that of converting a single piece, or any given portion of felspar, into china clay—bulk for bulk.

CHAPTER X

ANALYSES OF CHINA CLAY—METHODS OF WINNING AND PREPARING CORNISH CHINA CLAY

In the preceding remarks on Cornish china or porcelain clay, its origin, nature, characteristics, and composition have been noticed, and various opinions and theories referred to, and more or less briefly discussed, as to the species of granite* from the disintegration of which it is derived, and as to the felspathic ingredient thereof—whether orthoclase

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* The writer regrets having inadvertently overlooked a footnote in Mr. Collins' monograph of the *Hensbarrow Granite District*, in which, referring to the statements by many writers of protogene granite being abundant in the decomposed granite districts of Cornwall, he states that, whatever may be the case elsewhere, "there is certainly nothing of the kind at present known in Cornwall." This is certainly remarkable after the positive statements of Dr. Boase, quoted in the last chapter (p. 59), viz., that "protogene granite is, of all others, the most extensively disintegrated, in which state it is provincially called china clay, and that it abounds in St. Stephen's and the adjoining parishes, and in Tregonning Hill, near Breage"—another striking instance of disagreement as to observable facts by two competent observers, both intimately acquainted with the geology of Cornwall, and both of whom have written upon it. Cookworthy called the "caulin" a white *talcy* earth, found in Cornwall. Professor Sedgwick called the granite of Tregonning Hill chiefly a talcose granite (protogene), the talc sometimes white, but often of a pale yellow passing into light green. Mr. Henwood, too, says that in the north, central, and east parts of Cornwall the granite is sometimes very talcose, and that at Bedlam Green there is a formation of protogene. Dr. Page also says, in his *Handbook of Geology*, that protogene abounds in Cornwall, and that the china clay of Cornwall is chiefly derived from its decomposition.

(potash) or albite (soda) felspar, or an altogether distinct species, named by Professor Fuchs "porcelain-spar"—which, both from its composition, already given, and an analysis of it from Obernzell, in Bavaria, given in Bristow's *Mineralogy*, viz., silica 49·20, alumina 27·30, lime 15·40, soda 6·50, chloride of potassium 1·20, water 1·20 = 100·80, appears to be a soda-lime felspar—by the decomposition of which, and a new combination of its constituent ingredients, generally exclusive of the alkaline, this hydrated silicate of alumina has been produced. Differing statements as to the condition of the soft growan of Cornwall and Devon, and various opinions or theories as to the agencies by which that has been produced, and unsolved problems in connection therewith, have been mentioned, with the view of inviting further investigation on the part of readers who may have opportunities for observing the phenomena presented by the varying stages of the disintegration and decomposition of granite and the formation of growan.

Before proceeding to describe the processes by which the soft growan is worked, and the clay washed and prepared for market, it may be of some practical service to quote some analyses of porcelain clays from various localities, both English and foreign—reserving those of China and Japan till the next chapter, as these vary considerably in composition, and may be interesting to any who have not hitherto studied the variable composition of these clays.

In a former chapter the composition of fine Cornish china clay was given as silica 46·40, alumina 39·70, water 13·90; and an analysis of the finest quality, by Professor Ansted, was quoted, giving the proportions of silica and alumina respectively as 46·32 and 39·74; and also another given by him, with these ingredients, in the proportion of silica 44·60, and alumina 44·30; but with the remark, that the proportion of the latter in porcelain clays rarely reaches or exceeds 40 per cent. In an excellent treatise, however, by a writer whose name is not given,[1] but who appears to be well acquainted with the subjects on which he writes, it is stated (p. 32) that Wedgewood found by analysis that fine Cornish clay, in the state of an extremely white and fine powder, contained 20 parts of silica and 60 of alumina. It is very questionable if this could have been a correct analysis of any of the ordinary Cornish porcelain clays. It was more probably an analysis of a felspar, as Gehlen gives one of felspar from Kellberg, near Passau, showing its composition to be silica 63·0, alumina 20·0, besides potash, lime, and some iron, but the differences in the composition of the clays are certainly worthy of notice, by potters especially.

In the *Catalogue of Specimens in the Museum of Practical Geology, London* (p. 17), the following analyses of clay from Bluebarrow and St. Stephen's, Cornwall, made by Dr. Lyon Playfair, in 1852, are given, viz.:—

	Bluebarrow.	St. Stephen's.
Silica	45·52	46·38
Alumina, with peroxide of iron . . .	40·76	38·60
Lime	2·17	3·47
Potash, with trace of soda	1·90	1·77
Magnesia, phosphoric and sulphuric acids .	traces	traces
Water, with small quantity of organic matter	9·61	9·08
	99·96	99·30

Dr. Thos. Thomson, late Professor of Chemistry in the University of Glasgow, gives an analysis, made by himself, of china clay from St. Austell, as follows:—

Silica	37·10
Alumina	24·48
Carry forward . . .	61·58

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[1] *Treatise on the Origin, Progressive Improvement, and Present State the Manufacture of Porcelain and Glass.*" Longman & Co., London,

Brought forward	61·58
Lime	9·28
Ferric oxide	6·98
Water	19·22
Sp. gr. 2·484.	97·06

From the small percentage of alumina and the large amount of lime, and oxide of iron, this must have been a very inferior specimen of St. Austell clay.

Rose (Karsten's *Tablellen*, p. 37) gives the following analysis, without mentioning the locality, in which the alumina is certainly much in excess of the general run of Cornish clay, viz.—silica, 52·00; alumina, 47·00; oxide of iron, 0·33 = 99·33.

In Green's *Geology for Students*, the following analysis is given as that of the best china clay, viz.:—

Silica	46·32
Alumina	39·74
Magnesia	0·44
Lime	0·36
Ferric oxide	0·27
Water	12·67
	99·80

This is one of a pure and very infusible clay, but unfortunately, its locality is not given.

In Bristow's *Mineralogy*, the following analysis of the clay from Plympton, Devonshire, by Brogniart and Malaguti, is given, viz.:—

Silica	44·26
Alumina	36·81
Lime, magnesia, and potash	1·55
Iron and manganese	traces
Non-argillaceous residue	4·30
Water	12·74
Sp. gr. 2·25.	99·66

Mr. Collins, in his monograph (p. 29), quotes from the *Phil. Mag.*, vol. x., the following analyses of clays, by Dr. Boase, from the St. Stephen's and Breage mines, viz.:—

	St. Stephen's.	Breage.
Silica	39·55	40·15
Alumina	38·05	36·20
Magnesia	1·45	1·75
Alkalies, insoluble and soluble	8·70	9·50
Water	12·50	11·65
	100·25	99·25

And he gives the following analyses, made by himself, of clays prepared for the market, to show the variation which exists in the clays from different parts of the Hensbarrow district, viz.:—

From St. Stephen's

	A	B	C	D
Silica	45·00	45·10	46·86	46·44
Alumina	40·15	40·11	39·59	40·22
Lime	—	—	—	0·22
Peroxide of iron	0·35	0·60	0·27	0·25
Alkalies, insoluble and soluble	0·80	0·29	0·41	0·53
Water	13·70	13·90	12·87	12·34
	100·00	100·00	100·00	100·00

And from St. Austell, E and F, and from Roche, G.

	E	F	G
Silica	46·20	46·00	45·40
Alumina	41·10	40·10	40·30
Lime and Magnesia	—	traces	traces
Peroxide of iron	0·20	0·40	0·20
Alkalies, insoluble and soluble	trace	0·40	0·60
Water	12·50	13·10	13·50
	100·00	100·00	100·00

And for comparison he gives the following analyses from various localities elsewhere, chiefly in Devonshire:—

	From Devon, by Berthier.	Ditto, by Fownes.	Ditto, by Wagner.	Ditto, by Collins.	From St. Neot's, by Collins.
Silica .	50·51	47·20	10·00 free 34·00 combined	46·90	49·10
Alumina . .	38·18	38·80	36·80	38·35	40·20
Magnesia . .	—	0·24	—	trace	—
Peroxide of iron.	—	—	—	0·07	0·40
Alkalies, insoluble and soluble .	—	1·76	4·30	1·56	trace
Water . .	11·02	12·00	12·70	12·55	10·30
	99·71	100·00	97·80	99·43	100·00

The following analyses from several of the best European localities will enable comparison to be made with those from Cornwall and Devon, viz:—

	St. Yrieix.	St. Yrieix.	Seilitz.
Silica	46·80	48·00	58·60
Alumina	37·30	37·00	34·60
Alkalies	2·50	2·05	2·40
Magnesia	trace	—	1·80
Lime	—	—	—
Oxide of iron	—	—	—
Water	13·00	12·95	—
	99·60	100·00	97·40

	St. Tropez.	Meude.	Normandy.
Silica	55·80	63·50	50·00
Alumina	26·00	28·00	25·00
Alkalies	8·20	1·00	2·00
Magnesia	0·50	8·00	0·70
Lime	—	—	5·50
Oxide of iron	1·80	—	8·50
Water	7·20	—	9·50
	99·50	100·50	101·20

The variation of silica in the above analyses of Cornish and Devon clays, ranges from 37·10 to 52·00, and of alumina from 36·20 to 47·00, while that of the foreign clays, as given, ranges from 46·80 to 63·50 of silica, and from 25·00 to 37·30 of alumina, showing the latter to have a much higher mean percentage of silica, and a considerably less proportion of alumina in their composition. There are besides very varying percentages of alkaline ingredients, and of ferric oxides and other impurities, which, in the event of analyses of their clays not being got from and guaranteed by the clay merchants, shows the necessity of their being analysed before being used by potters who aim at certainty and regularity in the composition of their "bodies."

As has already been pointed out, the true porcelain clays of Cornwall and Devon differ from the pipe and potting lays of the Teignmouth and Poole beds—these latter being natural deposits," only requiring drying to fit them for market, and being all inferior in quality, so far at least as suitableness for the manufacture of hard porcelain is concerned, to the former. Although the term "deposits" is sometimes loosely applied to the porcelain clays, they are with rare exceptions[1] not deposits at all in the usual acceptation of that term, the soft growan from which they are obtained by water action being almost invariably the result of decomposition *in situ* of some species—whatever that may be—of the felspar of disintegrated granite, be that protogene, pegmatite, or some distinct species as yet unnamed, but which cannot correctly even be called "Cornish granite," as there are hard and durable granites in Cornwall as elsewhere, which are certainly quite distinct from that which furnishes the "growan."

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[1] Mr. Collins states that these occur only in one or two places in the nsbarrow district, such as that at Higher Carpella, in St. Stephen's, t Carloggas, near Foxhole Bridge—the former, in his opinion,

The disintegrated granite from which, by the decomposition of its felspar, china clay is obtained, is found in many localities in Cornwall, and also in Devon. It occurs, according to Mr. Collins, in areas of irregular form, generally much elongated and extending to an unknown depth, and is found in immense quantities in the western portion of the Hensbarrow range. It is universally associated with quartz, ore, and schorlaceous veins, which sometimes also contain oxide of tin. Many beds of it extend for a distance of a quarter of a mile, half a mile, or even more, in the direction of the veins, while their breadth may be only a few inches, and seldom exceeds one or two fathoms; very wide masses of it are wrought in many places, but these are invariably associated with groups of many parallel veins. Many of the clay mines, or open workings, such as that of the extensive quarry at Carclaze, were originally commenced for the sake of the tin in their numerous schorlaceous veins. The china-clay rock, "carclazite," occurs most abundantly in that immense open working, and in the neighbourhood of St. Austell, and is most largely worked, as stated in Mr. Quick's paper, previously referred to, in the parishes of St. Austell, St. Mewan, St. Stephen's, St. Dennis, St. Enoder, Roche, and St. Blazey; and on a smaller scale in the eastern

"resulting from the degradation and re-deposition of the natural clay rock of the higher grounds, and being only one or two fathoms in depth"; and the latter, "simply the mass of decomposed granite, which has bent over by its own weight, so as to occupy a pre-existing valley."

part of the county at Blisland and St. Breward, near Bodmin; and in the western part, near Helston: and in Devonshire, chiefly at Lee Moor, a part of Dartmoor, near Plymouth. Mr. Collins states that its occurrence is usually indicated to the practised eye by a peculiar depression of the surface, which is not observable where the china-stone rock alone occurs. It is found at all elevations, except the very highest, which, he states, are always composed of hard rock; its hardness being doubtless the cause to which the escape of these towering points from degradation is due. The carclazite resulting from the disintegration of the granite, contains, of course, more or less of its constituent ingredients, except those soluble ones (alkalies, silicates, etc.) which have been carried off by water action during the decomposition of its felspar, and consists of varying proportions of that mineral undecomposed, grains or irregular crystals of quartz, flakes of mica, sometimes a little schorl, and, finally, the completely decomposed felspar, which is ultimately more or less perfectly freed from all the other ingredients by the processes which will now, as briefly as possible, be described from the accounts given by Dr. Boase, Mr. Collins, and others, but which are more descriptive of the operations carried on prior to the great extension of the trade in recent times, and are now confined to the smaller clay works. Dr. Fitton described them (*Annals of Phil.*, vol. ii. p. 348) after a visit to Cornwall in 1807; and Mr. James Quick states, that with the exception of a few modern improvements, they are very similar to the methods pursued for many hundreds of years past in China. But as the principle is the same--however much the *modus operandi* now differs in large works—and sufficiently explains how the clay is separated from the other ingredients associated with it in the carclazite, it is given in preference to a detailed account of the much enlarged and more complex arrangements and apparatus employed in the large works, now so numerous in the clay districts, in which the production of clay is carried on on a vastly larger scale and by quicker and more efficient processes than those described underneath; for any adequate description of these space cannot be afforded here, but any of the readers interested in the subject will find full details of the whole in Mr. Collins' *Monograph.*

The first operation is that of removing the vegetable soil and substratum, called by the workmen the *overburden*, which consists of rock débris, sand, and impure discoloured clay. This, according to Dr. Boase, varies in depth from 3 to 5 feet, but, according to Mr. Collins, from 3 to 40 feet. The overburden removed, the clay[1] is worked in "stopes," being dug out progressively, by the aid of picks, in steps, resembling a flight of irregular stairs. The depth of the china-clay pits, as they are called, is various; but while fifty years ago it seldom exceeded twenty feet, shafts are now sunk to raise the clay from depths of 70 feet or more. The clay, when first raised, has the appearance and consistence of mortar, containing numerous grains of quartz, disseminated throughout in the same manner as in granite. In some parts it is stained of a rusty colour, from the presence of ferruginous veins and embedded portions of schorl and quartz. These are called by the workmen, *weed*, *caple*, and *shell.* These discoloured portions are carefully separated and thrown away, while the rest is conveyed to the floor of the washing-place or "strake," where it is thrown down on an inclined platform. On this a stream of water is made to fall from a height of about 6 feet or more, while the workmen constantly turn over the material with piggles and shovels. By this process a large quantity of "sand" is at once separated and deposited in an oblong trench beneath, from which it is shovelled away continually. As from three to eight tons of sand are produced in getting each ton of clay, its removal in the cheapest possible manner is a matter of great importance. The trench is also inclined, and ends in a covered channel that leads to a series of catch-pits and ponds into which the rest of the clayey material is carried by the running stream. The pits are 5 or 6 feet square, or 8 feet by 4 feet, and 4 feet deep, their sides and bottom (as are those of the ponds also) being lined with cut moorstones, laid in waterproof cement. In the first pit the grosser particles of mica and other undecomposed materials, not retained in the trench, are deposited, and being of a mixed nature are rejected, at the end of each day's work, by an opening, provided for the purpose, at the bottom of the pit. When the water has filled the first pit it overflows into the second, and in like manner into the third, and so on. In the second, and perhaps the third also, the fine mica is deposited, and is often retained and sold at a low price under the name of mica clay. These pits are hence called the "micas." The clay held in suspension by the water, overflows from these into the last pit, where it is partially deposited; and thence into the ponds. These are of the same depth as the pits, but about three times as long and wide, generally about 20 feet long by 12 feet wide. The suspended clay can be procured of greater or less fineness, according to the extent to which it is carried in suspension before its final deposition in the ponds, and when it is finally allowed to settle, the clear supernatant water is run off by plug holes on the side of the pond, the process being carried on till a sufficient deposit of clay is accumulated.

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[1] The term "clay" is applied in the clay districts indiscriminately alike to the carclazite and to the clay washed out of it.

Mr. Henwood, M.E., in a brief memoir, published in the *Report of the Royal Polytechnic Institute, Cornwall*, in 1840, states, that when, either owing to rainy weather or other causes, the clay does not settle in the ponds, it is watered with a solution of alum, to hasten its deposition, and Mr. Stocker states, in a paper read to the same Society, that any saline solution will produce that effect.

It may interest our readers to note here the composition of the carclazite made by mechanical analysis of two fair samples —one, (A) from Great Treviscoe in St. Stephen's, and the other (B) from Cleytane, in St. Enoder, given by Mr. Collins (*Monograph*, p. 28), viz.:—

	A	B
Water	5·0	5·5
Coarse sand and mica (shell)	67·5	71·5
Fine sand and mica	2·0	2·5
Fine mica and some clay	3·5	3·0
Fine clay	22·0	17·5
	100·0	100·0

The net mean product of clay from the soft growan being, from the above analyses, somewhat less than a fifth, or 20 per cent.

The fine clay, after the water has been as completely as possible run off, remains in the ponds in the state of a fine paste, and is then transferred, generally by hand-barrows, into shallow pans about 40 feet long by 12 to 15 feet wide, and from 14 to 18 inches deep, lined also with cut moorstones. As may be inferred from the much more extensive scale on which operations are now carried on in large works, all the pits, ponds, drying pans, etc., are of much larger measurements than those given above.

Some works are so laid out that the partially consolidated clay has to be pumped into the drying-pans, and Mr. Henwood, in reference to this process, says: "I noticed, with surprise, that clay sufficiently consistent to stand in a heap, will run through a common suction pump worked by hand, though when so drawn it requires to be raked from the pump-head."

When the pans are nearly filled the clay is levelled, and is then left undisturbed till it is nearly dry. The time required for this part of the process depends in a great measure on the state of the weather, and is a tedious process in the damp climate of the west of England, the pans being exposed to the air—during the summer, four months or less may suffice, whilst at least eight are necessary during the winter—often from September to the following May. When sufficiently dry the clay is cut into cubes or lumps, 9 to 12 inches on the sides, which are then carried to the drying house, an oblong shed, the sides of which are open wooden frames so constructed as to keep out rain, but admitting the free passage of air, and of exposure to the sun in fine weather. The clay when dried is scraped perfectly clean, and is then ready for being sent off for shipment in bulk, or, when requisite, in casks. The scrapings and waste are wheeled back to the "strake" and re-washed.

In 1807, when Dr. Fitton visited Cornwall, he found only seven clay works in operation in the parishes of St. Dennis and St. Stephen's; the largest of which only produced some 300 tons per annum. The consumption and demand for china clay has since then so enormously increased, however, that in the Hensbarrow district alone there are now probably about 100 works, many of the larger ones turning out from 2500 to 8000 or 9000 tons each yearly. Mr. Collins mentions that in 1874 one of the largest works near St. Austell produced 9000 tons, employing thirty men, while many others produced 6000 tons each, employing twenty men. To meet the enormously increased demand—arising not merely from the extension of the pottery trade, but to a large extent also from the various uses to which china clay is now applied in other trades and for other purposes — different methods from those described above became necessary; the one most generally adopted being that in which the clay is raised from pits by the sinking of a shaft to the depth often of 10 or 12 fathoms, and the driving of a level from its bottom to where a rise is put up through the clay to surface, in which a "button-hole" launder is placed, and y which the clay, after being by an ingenious contrivance ed with water, is conveyed down to the level and along it to the bottom of the shaft, from which it is pumped to surface or lifted at once high enough to allow of all the subsequent operations—similar, but on a much larger scale, to those above described—being carried out by gravitation.

The other method of working is adopted in cases where the bed of clay is situated on a hillside, with plenty of space below. In that case an adit level is driven into the hillside, or from the valley, to the required depth, and a rise put up as before; with some modification of the launder arrangements the clay in suspension in the water makes its exit in the valley, and is there purified, settled, and dried, as already described—the works being laid out on a lower level than the adit.

In the large works the clay is now finally dried—although by no means to the improvement of its quality—by artificial heat, in a large building called the "dry" (which consists of two parts, the "dry" proper and the "linhay"), which Mr. Collins describes. As brought into the "dry" the clay usually contains about 50 per cent. of water, which is reduced to about 12 or 14 per cent. by the time it is thoroughly dried. To get it into the "linhay" ready for market Mr. Collins estimates its cost at 8s. 6d. or 9s., which with dues, transit, agencies, and sundries, is increased to a total average cost to the clay merchant of about 16s. or 17s.

While most of the large china clay works are now carried on by sinking pits and shafts, open workings are still to be met with, of which the largest and most interesting is that of Carclaze. It has a character of its own, and has been often described; but as many may not have seen it, or a description of it, one by an observant foreigner may interest them.

This gentleman, Alphonse Esquiros, visited it some eighteen years ago, and described it in an account of Cornwall,[1] published by him. In writing of the clay works, he says: "Some of these works are very interesting, and employ a large number of persons—men, women, and children. The women have white bonnets, white sleeves, and white aprons, and it is curious to see them carrying to the surrounding hills a clay whiter still, which they artistically expose to the sun-beams. One of the most curious of the mines is that of Carclaze, two or three miles from St. Austell, a small town with a fine old church. A road runs to a large common all covered with furze and gorse. As the bushes were studded with golden flowers, I did not complain of the sterility of the soil; and, besides, the sea could be seen in all its grandeur at a certain distance. All at once an abyss opens in the gloomy common, before which you halt in stupefaction. The origin of this prodigious excavation, which is at least a mile in circumference, and more than 150 feet in depth" (and is probably much larger and deeper now), "and has been attributed by the ignorant to the intervention of Satan, by the learned to the Romans or the Anglo-Saxons. It is not a mine properly so called, but an open quarry; the workmen are 'streamers,' that is to say, men who obtain tin by washing the deposits from the disintegration of the rocks. The interior of this abyss, whose greyish whiteness contrasts with the colour of the common and the brown surface of the moors that surround it, displays masses of granite decomposed by certain influences which are not yet thoroughly known." After a description of the tin workings, he proceeds: "In the same excavation, but on the other side of the quarry, and facing the tin workings, a torrent, at first yellow, but which soon changes its colour and becomes of a milky white, falls over projecting rocks. Men armed with picks feed this torrent, by casting into it lumps of white earth. After running thus to the bottom of the abyss, which it crosses at one bound, the stream suddenly disappears nder an arch. You might suppose it lost, but it can be easily l again; to do so, it is only necessary to go five or six yards along the common and find a fresh scene of operations. Here the white stream is received in reservoirs or cisterns. The milky fluid, by remaining still, deposits at the bottom of these cisterns a sort of cream, above which the water is perfectly limpid and blue. The action of the wind and sun is sufficient to evaporate the water in a few months." (Mr. Esquiros, however, has overlooked the running off of the supernatant water.) "The white clay is then cut out with spades and is carried to open sheds to dry; it there hardens and forms the matter used in making china."

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[1] *Cornwall and its Coasts*, by Alphonse Esquiros, Esq., author of *English at Home*. Chapman and Hall, London, 1865.

Carclaze mine is now chiefly wrought for china clay, but, Mr. Collins says, still yields notable quantities of tin. It was in full work as a tin mine in the reign of Henry VII. Its area was computed by Mr. Henwood in 1843 at 5 acres. According to Mr. R. Symons, of Truro, who surveyed it five or six years ago, it was then 13 acres. There is an interesting account of this mine in the *Intellectual Observer*,[1] written by Professor Church, who states that it was not till towards the close of the last century that the earth, or soft rock, of which the whole place seems to consist, was recognised as china clay. He mentions that the supernatant water in the tanks, after the clay has all settled, is of a beautiful greenish-blue colour. Referring to the mineral substances in the native claystone, he also says, that a yellow-green talcose mineral is the most important of these. He refers to the complete absence of all the usual signs of mining operations as you approach Carclaze, and says that, as you cross the moor, you are, without knowing it, close to the mine, which is unseen till you reach the grassy edge of the great pit. It is approached from St. Austell by a hilly, deep, and winding lane, which passes close by the west end of St. Austell Church, and brings you out upon the moor; bright, and usually breezy too, in summer, but very drear in winter. White roads intersect the moor, along which Professor Church says, pass continually towards the sea, three miles distant, waggons and carts laden with square blocks of a substance of dazzling whiteness. His description of Carclaze and what he saw there will interest anyone who may refer to it, especially as it is accompanied with a coloured view of the moor and the mine.

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[1] *Intellectual Observer*, vol. ii. p. 401. Groombridge, London, 1869.

CHAPTER XI

CHINESE KAOLIN—HISTORY AND COMPOSITION

IN treating of Chinese kaolin, the writer is sensible of how very imperfect our knowledge still is regarding the materials used by the Chinese in the manufacture of their unrivalled porcelain. From the written annals of Feouleang, a city belonging to the same district of the Empire as King-te-chin—the great seat of the porcelain manufactories—it appears that the date of the origin of the art of making porcelain is unknown, but it is stated therein that from a date answering to A.D. 442, the latter city had enjoyed the honour of supplying the imperial city with porcelain, and the invention of the art must have occurred at a much earlier period. It is stated by Julien,[1] that its manufacture was commenced in China in the district of Sin-p'ing (province of Ho-nan), under the dynasty of Han, some time between B.C. 185 and A.D. 87; and that as early as A.D. 600, porcelain was in common use throughout the country, and consequently the manufacture must, even then, have been on an extensive scale.

In the face of such facts as these, from which it may be safely assumed that the manufacture of porcelain has been carried on in China for somewhere about 2000 years (although some writers question this, and restrict the period of its manufacture to 1500 and even to 1000 years), it certainly does seem remarkable that we still owe nearly all our knowledge regarding the materials used by the Chinese potters to very imperfect information obtained by one or two Europeans, who, from want of all practical knowledge of the art of pottery, and from their ignorance of its technicalities, were incompetent and unable—even had greater facilities been at their command for obtaining them—to furnish such reliable details as might have enabled our manufacturers ere this to rival the porcelain of the Chinese. Some scanty information may be found in the account given by Marco Polo,[1] the celebrated Venetian traveller, who, in the thirteenth century, resided for some time in China, and saw at Kin-sai the manufacture of porcelain. He states that the manufacture was carried on to a vast extent, and adduces as proof of its cheapness, even at that early date, that eight porcelain cups could be purchased for a Venetian groat. He mentions the fact of the prepared clay—which in China is first kneaded in pits by the feet of the workmen, and then by hand in smaller quantities—being left exposed to atmospheric influences for many years. This practice is one to which Chinese potters evidently attach much importance, the prepared clay being frequently kept for fifteen or twenty years; Dr. Watson (in his *Chemical Essays* already quoted) says, for "twenty or thirty years" before being used. The longer it is kept the more valuable it is considered, and instances are not uncommon of provident parents preparing sufficient clay to last their sons for their lifetime. In an article on "China and Earthenware," in *The Pottery Gazette* for May 1883, it is stated that instances are not unfrequent of a Chinese potter making his wares of clay first prepared by his grandfather.

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[1] *Histoire et Fabrication de la Porcelaine Chinoise; Ouvrage Traduit du Chinois*, par M. Stanislaus Julien. Paris, 1856. Translator's Preface, p. 20.

This practice of a lengthened mellowing of the slip is one which it would be well if our manufacturers could follow to a greater extent than is customary in Europe, as no amount of pressing, kneading, and slapping, or other mechanical processes, n possibly solidify it so perfectly as that of leaving it for a lengthened period to the solidifying and mellowing effects of atmospheric influences, the longer exposed to which the more free of air-bubbles, and the more homogeneous the dried slip, becomes and the more perfect, of course, the wares made from it.

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[1] *Marsden's Translation*, 4th edition.

As mentioned by another contributor to *The Pottery Gazette*,[1] the Museum of the Royal Society had, previous to Cookworthy's discoveries of Cornish china clay and stone, specimens of the Chinese kaolin and petuntze, which had been presented to it by Dr. Sherard, a traveller in China, and which, the above contributor states, had suggested to Cookworthy the examination of the granier (or granen) of Cornwall for similar materials. He further states that, according to Cookworthy, the felspar, which in the white granite of Cornwall is combined with quartz and mica, supplies the most essential component of Oriental china. In the same article, the writer mentions the discovery by Mr. Ryan, F.S.A., "in a deserted lead mine, of felspar in the two states, which the Chinese call kaolin and petuntze, or rock and clay." When and where (although the locality was probably Cornwall) is not stated, but in an article already quoted, the writer of it gives the date of Mr. Ryan's discovery as 1834, and states that the clay possessed all the essential qualities of the Japan kaolin. Both of these materials were used by Mr. Josiah Spode for many years.

The writer called lately at the Royal Society's rooms, in the hope of seeing the specimens above referred to, but was informed by the secretary that the whole contents of the museum had, many years ago, been presented to the British Museum. On going there, Mr. Fletcher, the curator of the mineralogical department, informed him that the presentation by the Royal Society must have been before his appointment, as he had never heard of it; but he obligingly offered to search the private drawers under the cases containing the kaolins and other silicates of alumina, and in one of them we found a tray with a specimen of china clay, below which there is an old faded scrap of paper, on which is written in ink, quite brown from age, not "kaolin," but "petuntze"—this very probably being one of the specimens presented to the Royal Society by Dr. Sherard, although, of course, the label may have got misplaced.

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[1] "Progress of Pottery Manufactuure," No. II. April 1883, p. 347.

In the *Catalogue of Specimens in the Museum of Practical Geology*, which has been several times already quoted, it is said (p. 9) that it is probable that the general composition of the artificially prepared clays employed by the Chinese for their porcelain has long remained the same, so that by an examination of those now employed we may obtain a fair knowledge of those formerly used. This was written nearly twenty years ago, but to this day, notwithstanding the Chinese Empire having been since, and during most of that time accessible everywhere to Europeans, who have penetrated to its most remote parts, we have still, so far as the writer can ascertain, no reliable information whatever regarding the ingredients of Chinese porcelain and their composition later than the very superficial and imperfect information furnished by the Jesuit father, Francis Xavier D'Entrecolles, who, early in the eighteenth century, was residing as a missionary at King-te-chin. In the treatise referred to in the last chapter, and from which the writer quotes some interesting details in this article, the author states that D'Entrecolles contrived to elude the jealous vigilance so generally practised then towards strangers in that country, and that he not only obtained specimens of the earths used in the composition of their porcelain bodies, but also acquired some knowledge of the processes employed in its manufacture at King-te-chin. He states also that a very circumstantial letter was written by the learned father on the subject, which was published by Grosier in his general descrip-
n of the Chinese Empire, but, owing to the want of practical
ledge on the part of D'Entrecolles, his descriptions "proved
ctive in many particulars as to afford little or no

assistance towards a knowledge of the ingredients used for Chinese porcelain"; and yet, defective as his descriptions are, they have been the only ones available to potters and students of the subject during the 170 years or so which have elapsed since they were published—during which time they have been repeatedly quoted by numerous writers as if they were full accounts and perfectly reliable. In the *Catalogue of Specimens in the Museum of Practical Geology* (p. 9), it is said that, according to the Père d'Entrecolles, the chief ingredients of Chinese porcelain are kaolin and petuntze; and, it is added, it is generally believed that the former is decomposed felspar, but the definition of the latter is involved in more difficulty. *Pe-tun* signifies a white paste, and the suffix *tze* is merely a diminutive applied to the material when made into the usual form of small cakes or bricks (those of a yellow earth being called *hwan-tun-tze*, and those of a red material *hon-tun-tze*); and it appears, indeed, that several substances used in the manufacture are prepared in the form of white tablets, and pass under the common name of *petuntze*, which term only indicates colour and size, and nothing whatever of their composition. By D'Entrecolles, however, it was assumed to be restricted to the fusible ingredient of the porcelain paste, and therefore it has generally been considered to denote a substance resembling our Cornish china stone (although no analysis of it, with the exception of one of a Japanese porcelain-stone given by Janviers—and which may or may not be identical with petuntze—so far as the writer has seen, has ever been published), which is an aggregate of felspar, usually more or less decomposed, and quartz, commonly associated with a talcose or alkaline substance—in fact, a disintegrated granitic rock, protogene or pegmatite; and in a footnote (p. 9) it is said that "it is probable that some confusion has arisen in the application of the terms 'kaolin' and 'petuntze,' and that they are not used in the same sense as that in which they are employed in China."

Other quotations from various authors could be given, to show, not only that some uncertainty exists in reference to this material, petuntze, but even that the opposite of the generally received opinion about it is held by some, as for instance in *Dodd's Dictionary*,[1] where it is said that a "peculiar kind of granite called Cornish stone was, somewhere about a century ago or more, found to be almost identical with the kaolin, or porcelain earth employed by the Chinese. This," it is added, "was a great step towards the naturalisation of the manufacture in this country." In this passage china stone is identified, not with the petuntze, but with kaolin.

The communications of D'Entrecolles excited much interest at the time of their publication, and led to the celebrated Reaumur undertaking a series of investigations with the object of ascertaining in what the superiority of Chinese porcelain consisted. He procured specimens of Chinese, Saxon, and French porcelain, which he broke, and found the internal structure of both the two former to be compact, smooth, and shining, while that of the French was less close and fine, and without lustre, and its grain resembling crystalline sugar. He next tested them by exposure to such extreme heat in a crucible that all the European specimens were melted, while the Chinese remained unaltered. This most essential difference led Reaumur to the discovery of the true nature of porcelain, which s a semi-vitrified compound, in which one portion remains infusible at an extreme heat, while the other portion vitrifies at that heat, and, enveloping the infusible part, produces that smoothness, density, whiteness, and, in the case of china-ware, transparency, which, with a fine texture of the glaze (resembling the lustre of velvet rather than of satin), is characteristic of e finest descriptions of porcelain. Macquer, however, in his *mical Dictionary*, questions the correctness of Reaumur's sions, and it is probable that the Saxon specimens he experimented upon were not made of the best materials; Macquer asserting that the clay and other ingredients of the porcelain of Saxony are similar to those employed by the Chinese, one portion being absolutely infusible; and in this he is corroborated by the writer already quoted,[1] who says that "the Dresden, or Saxon, china has some qualities which render it decidedly superior to the Oriental"; and after describing its materials and texture, adds, that "it is not fusible by any heat employed in firing." This may be so, when it is only subjected to the extremest heat of European kilns; but the heat to which Chinese porcelain is usually subjected is so much greater, that it is said that some of the materials employed in the Chinese glazes cannot be vitrified at a lower temperature than would suffice to fuse granite. The Chinese porcelain glaze is much superior to any used in European potteries, and requires such extreme heat for its fusion—the object aimed at being to render it perfectly impermeable to moisture from the ware in firing, which is necessary, owing to the Chinese subjecting the greatest part of their porcelain to only one firing, previous to which the ware is dried sufficiently in the air to prepare it for glazing. This plan, superseding the separate biscuit and glost firing of our potters, must secure a great saving in time and cost of firing, besides in that of breakage and other losses in the kilns; but it is unattainable by our porcelain manufacturers, owing, if for no other cause, to the inferior refractories of the fire clays they use for saggers, a reference to which was made by the writer in his article on "Fire Clay," in *The Pottery Gazette* for December 1883.

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[1] *odd's Dictionary of Manufactures*, article on "Porcelain."

Reaumur, in his experiments with the specimens of kaolin and petuntze received from China, reported to the Academy of Science, that while the former gave no indication of fusion in a porcelain furnace, the other was fused without any addition of fluxing materials; but owing to the want of authentic analysis of both these materials there is evidently a great deficiency of reliable information as to their exact composition. The writer on "China and Earthenware" in *The Pottery Gazette*, already quoted, says that petuntze is obtained by abrasion and from "fragments of a rocky mineral, of which the greenish is the best —now proved to be felspar, with a small portion of protosulphate of iron," and he then proceeds to indicate, rather than describe, the processes by which it is reduced to an impalpable powder, and formed into cakes, in size and thickness much like floor tiles. He states, however, that kaolin also is "obviously felspar found in beds reduced by atmospheric action to the state of clay; and that it is so named from being found in a state, by nature, almost ready for the manufacturer." That this is not the origin of its name is well known, it being derived from its original source, as stated below. The same writer, referring to china and porcelain as well as to earthenware, says that its "hardness, infusibility, and unalterability require the presence of flint"; and again, "silica, when pure, is transparent, and when calcined loses much of its adhesive quality, and even in the pulverised state communicates to the ware hardness, firmness, and unalteration by firing." Now, as evidencing the confusion of ideas in respect to the composition of the ingredients of porcelain, and of kaolin and petuntze, respectively, the author of the *Treatise on Porcelain*, quoted in the last chapter, says: "It is the kaolin which, although much softer than the petuntze when taken from the quarry, gives strength and body to the porcelain, and consequently this, or some substitute possessing the same quality, forms an indispensable ingredient in its composition." He adds that "it is related that some Europeans, having privately obtained some blocks of petuntze in China and conveyed them to their own country, vainly endeavoured to convert them into porcelain; which, becoming known to some Chinese manufacturers, they deridingly remarked, "That certainly the

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[1] "China and Earthenware," *The Pottery Gazette*, May 1883, p. 441.

Europeans must be a wonderful people, to go about to make a body, whose 'flesh' was to sustain itself without 'bones'" (p. 109). This story appears somewhat apocryphal on the face of it, but, if true, does it not rather indicate that petuntze is at all events not identical with china stone, which can by itself make a passable body; and that more probably kaolin was the material—the attempt to make a porcelain of which, without a siliceous ingredient, excited the mirth of the Chinese manufacturers? The simile they used (if they did use it) was not a very appropriate one, but certainly our china clay would be more appropriately called the "flesh," and flint the "bones" of porcelain, than would the reversal of these terms. The same author states that kaolin is found intermixed with particles of a shining substance resembling mica (p. 105), and again (p. 109) that it is known from the particles of mica which it contains, to have its origin in felspar, or (? of) graphic granite (pegmatite). Those two rocks, felspar and pegmatite, are not at all similar; and it will be shown that kaolin is not derived from a granitic rock at all.

It has been stated by the Baron von Richtofen[1] that it seems uncertain now whether the Chinese use, in making porcelain, what we call kaolin, for the mineral they obtain from Kau-ling, the locality from which their kaolin was originally got, and from which it has been named, is a greenish rock (Yeou-ko), as hard as felspar, which they reduce to a fine powder by stamping and other processes, after which it is moulded into small bricks. He adds, "that formerly the best quality came from Kau-ling, but that this place has lost its prestige for centuries; nevertheless the Chinese still use the term for the best of this material, from whatever locality it is got." Unfortunately the Baron gives no information as to the localities from which the factories (500 or more in number at the time D'Entrecolles resided there) at King-te-chin now obtain their supplies. He states further, "that the application of that name, by Berzilius, to porcelain earth, was made on the erroneous supposition that the white earth he received from a member of the embassy occurred naturally in this state. *The same kind of material is called petuntze.*" Its composition is given by Janvier,[1] from an analysis by Ebelman and Salvetat, as—

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[1] *American Journal of Science*, March 1871, p. 179.

Silica	75·09
Alumina	14·02
Magnesia	traces
Potash	2·09
Soda	3·05
Ferric oxide	0·08
Lime	0·05
Ox. manganese	0·03
Water, combined	2·03
	96·44

In the work of Stanislaus Julien, above quoted, there is an appendix containing a short "Memoire sur la Porcelaine du Japon," by Dr. J. Hoffman, describing the porcelain quarries of Japan, in which he states that the "terre blanche," or "terre à porcelaine du Japon," which is used for the fabrication of porcelain, comes from the mountain Idzumi Yama, and is white, but as hard as rock, and has to be broken with hammers, and pulverised in mills. Its composition as given by Janvier, from an analysis by Malaquti, is—

Silica	75·09
Alumina	20·00
Potash	3·05
Lime	0·06
	98·20

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[1] *Practical Keramics*, by C. A. Janvier, p. 34. Chatto & Windus, London, 1880.

From the large percentage of silica and the percentages of alkaline ingredients in these two analyses, it may be assumed that these are the analyses of very siliceous felspars or petrosilexes, rather than of the porcelain clays obtained from them, of which they are given as analyses; but the more the matter is looked into, the more uncertainty appears attached to it, and it is very much to be regretted that some persevering attempt has not been made ere now, either by the Chamber of Commerce in the Potteries, or by the authorities of the Museum of Practical Geology, London, to obtain both from China and Japan certified specimens of the various minerals which are used as ingredients of their porcelain wares, and of which reliable analyses could then be had for comparison by our porcelain manufacturers, with those of our Cornish and Devon china clay and stone.

CHAPTER XII

CHINESE KAOLIN—PETUNTZE

IN the *Treatise on Porcelain*, quoted in the last chapter, and already referred to, the author states (p. 105) that the Chinese kaolin and petuntze "are found in mines or quarries situated between twenty and thirty leagues from King-te-chin, to which they are brought in small vessels, which are continually passing up and down the river of Jao-tcheou for that purpose," and he further states "that the hard blocks of petuntze are cut from the quarry in the form and about the size of our bricks, and are brought in this state to King-te-chin."[1]

He describes the methods by which the petuntze is reduced to a sediment and dried in moulds and afterwards cut into square pieces, which are sold by the hundred to the porcelain makers. He states also that "similar processes are followed in the preparation of the kaolin, but this substance being much less hard than petuntze, less labour is required for its performance." In this account the kaolin and petuntze—which are the prepared materials, and appear to be prepared for use, not by the porcelain manufacturers, but by parties who make their preparation a special business—are evidently confounded with the rock minerals from which they are produced. The author further states that two other substances, described as oil (a Chinese term for an alkaline preparation of lime, but which contains no oil) and varnish, are used in the manufacture of porcelain—one of these is "a combination of petuntze (?petrosilex) with another substance," the name and composition of which is not given, but "to each one hundred pounds of which, after being reduced to a creamy condition, one pound of a mineral called 'she-kao,' or 'chy-kao,' which is a kind of gypsum, is added." The other is "a thin paste of lime and potash obtained from quicklime and fern ashes," the latter fluxing the lime, and, "to dissolve this mixture she-kao is also added in the same proportion as to the other. To the agency of this oil of lime the Chinese manufacturers attribute all the lustrous appearance of their porcelain. In mixing these two varnishes together, one measure of the oil of lime is added to ten measures of that of petuntze." The same author states that since the time when D'Entrecolles communicated his observations on the porcelain manufacture in China, the potters there have discovered a new mineral which they can advantageously use in the manufacture of porcelain. It is described by him as a species of chalky (or calcareous) stone, "which bears some outward resemblance to soap, and is declared to possess considerable medicinal virtues. It is called 'hoa-che'; and when used instead of kaolin, the result is a porcelain of very fine grain, and much better qualified for receiving colours, but more brittle and far dearer in cost than the common porcelain, the price of hoa-che being three times that of kaolin." The hoa-che is very probably a species of steatite, a silicate of magnesia, and which is capable of being made into porcelain without any admixture of other materials, as the author affirms can be done with hoa-che.

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[1] Although the writer has followed Janviers and other recent authorities hitherto in the spelling of this name, he may as well mention, that in a v map just issued by the China Inland Mission, it is spelt "King-te-g."

Now it would naturally be expected, that, having a Museum of Practical Geology here, which has been in existence for many years, anyone desirous of learning something of the clays and other ingredients employed by the Chinese and Japanese in the manufacture of their porcelain, would find specimens of all their materials there, with analyses of them attached. Strange however as it may appear, it is not the less a fact, that all our Government Technological Museum can show is a few small specimens, not obtained through official agency, but which have been picked off the materials being conveyed by the vessels from the quarries to the neighbourhood of King-te-chin, or from the carts conveying them from the vessels to the works, by someone who probably was unable to tell correctly what the several specimens really were. These, such as they are, have been forwarded to the Museum by W. Lockhart, Esq., to whom therefore all the scanty means at present available for any practical knowledge of Oriental porcelain ingredients are due; but even of these no analyses have yet been published. The writer, by the courtesy of Mr. Rudler, curator of the Museum, has lately been allowed to inspect these specimens — of which, however, little can be made without analyses. Amongst them is a small specimen about 1½ inch long, by 1¼ broad and ½ of an inch in thickness, which is a hard mineral of a greenish-yellow tint, and labelled as the mineral from which the Chinese kaolin is produced; whether it is identical with the mineral "Yeou-ko," of which Janvier (in his *Practical Keramics*, p. 34) gives the analysis quoted on p. 96, *supra*, the writer has not yet been able to ascertain, but there is no doubt that it is a petrosilex and not a granitoid mineral such as Cornish china clay is obtained from. Janvier, from the best information, says (p. 149), it may now be inferred, "that most Chinese porcelains have a strictly petro-siliceous basis, and that the term kaolin is applied by the Chinese to a washed, pulverised petrosilex, and not to the clay we call kaolin"; and therefore, from this and the various quotations already given from other sources, it would certainly, the writer presumes to think, be an advantage gained to the nomenclature of porcelain manufacture, if the term kaolin was dropped as a name for our china clay, and that of carclazite substituted, as proposed by Mr. Collins.

As may be inferred from the foregoing remarks, there are few available sources for obtaining reliable analyses of the ingredients of Chinese porcelain, but leaving over in meantime any that it may be possible to obtain of its other ingredients, the writer will now give all the analyses of Chinese kaolin, which have come under his notice. Should any readers be in possession of others, or be able to refer to sources of obtaining them, they will confer a favour by sending them, under cover, to the publishers.

The author of the *Treatise on Porcelain Manufacture* states (p. 109), that the kaolin quarries of China are similar to the mines of Alençon, and St. Yrieix near Limoges, where a similar porcelain earth is found—all of them having a superstratum of red, friable, micaceous rock, of the texture of gneiss. From his statement, however, it is really difficult to determine when he is referring to the clay, and when to the rock it is obtained from. He gives no analysis of the kaolin, but states its composition to be—

Silica	52·00
Alumina	42·00
Oxide of iron	0·33
	94·33

but the writer believes this is not likely to be correct—the percentage of alumina being much in excess of the percentages given in all the other analyses.

In Bloxam's *Chemistry*, p. 285, it is stated that the Chinese kaolin contains "a considerable portion of free silica" (which is doubtful), "along with variable percentages of lime, magnesia, and oxide of iron," and the following analysis of it is given, viz:—

Silica	50·5
Alumina	33·7
Potash and soda	1·9
Oxide of iron	1·8
Magnesia	0·8
Water and loss	11·3
	100·0

In Ure's *Dictionary of Arts*, vol. iv. p. 512, a similar analysis is given of kaolin from Si-king, in China—evidently of the same clay as the foregoing, as the analyses are exactly alike. Neither of these gives the source from which they obtained their analysis, or by whom it was made.

In the same dictionary, however (vol. i. p. 204), is given the following analyses (investigated by W. Kulman) of three qualities of kaolin from Kiu-kiang, in the form of bricks dried at 110° C., and of course not deprived of their constituent water:—

	No. 1.	No. 2.	No. 3.
Silica	50·637	52·208	51·210
Alumina	32·737	31·997	33·150
Oxide of iron	0·955	0·712	0·709
Ferrous oxide	1·690	1·911	1·936
Ox. manganese	0·827	0·540	0·843
Lime	0·501	0·464	0·456
Magnesia	0·268	0·273	0·284
Potash	2·520	1·560	1·403
Soda	traces	0·970	0·992
Water	10·011	9·499	9·500
	100·146	100·134	100·483

Lyell[1] gives the undernoted analysis quoted from Phillips'

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[1] *The Students' Elements of Geology*, by Sir Charles Lyell, 2nd ion, 1874.

Introduction to Mineralogy, of Kaolin from King-tah, China, viz:—

Silica	71·15
Alumina	15·86
Lime	1·92
Water	6·73
	95·66

And it is probable that this analysis may much more correctly represent the character of much of the Chinese kaolin than the first one given, because their porcelain bodies contain a much larger proportion of silica and less alumina than does English porcelain, both their kaolin and petuntze being obtained from very siliceous rocks.

It will be seen from a comparison of the above analyses of kaolins from Kiu-kiang that they have larger percentages of silica than the Cornish and Devon china clays, of which analyses have been given; while, on the other hand, all the analyses of Chinese kaolins given above, with the exception of the last, have less percentages of silica than several of the china clays of France and Saxony, analyses of which have been given.

Janvier says that the "best Chinese porcelains appear much the same in texture as the European hard porcelains, differing, however, in the composition of both the paste and glaze," and further, that, "having a much greater proportion of silica, they are more fusible than the fine European pastes, which are very aluminous, and consequently very hard." A comparison of the analyses, however, of their kaolin, with those of the Continental clays, shows, as has just been stated, that at least some of the latter have a considerably larger percentage of silica than the Chinese kaolin—unless the analysis from Phillips' *Mineralogy* is to be taken as their standard; and that the Chinese porcelain, if much more siliceous than the European, derives its excess of silica probably from its petuntze ingredient.

Janvier proceeds to say that the Chinese paste, and still more the glaze, will melt in the greatest heat of the European kiln. This and the preceding statement are so diametrically opposed to the statements the writer quoted from Reaumur, and from other sources, that, not having himself much practical knowledge of porcelain manufacture, he cannot offer any opinion of his own as to which is correct; but would urge the diversity of statements in the matter as a proof of the desirability of specimens of the Chinese and Japanese porcelain materials, and of their porcelain, with accompanying analyses, being obtained and placed in the Jermyn Street Museum for the benefit of the trade.

The writer has been unable to find any reliable information regarding the ingredients of Japanese porcelain except from Janvier, who, in *Practical Keramics*, already quoted, gives the following analysis of "Terre d' Porcelaine du Japon" by Malaguti, viz.:—

Silica	75·09
Alumina	20·00
Potash	3·05
Fluorvine	0·06
	98·20

and mentions quartz, felsite (or petrosilex), felspar, and a peculiar porcelain stone from Arita, as other ingredients of Japanese porcelain. Janvier says that the Japanese have surpassed their teachers, the Chinese, and are now the best potters and decorators in the world; in delicacy of finish and in perfection and harmony of colour they are unsurpassed. According to their own authorities, they derived the art of porcelain manufacture from the Chinese. In the sixteenth century, porcelain was first made at Hizen under the direction of Gorodayu Shonśui, who went to China to learn the art, while, about the same time, several porcelain makers were brought over from the Corea by Prince Nabesshima Naoshige. The art had been, some time previously, introduced into the Corea from China, and had there attained such perfection, that both China and Japan acknowledge their obligations to that country. Genuine Corean porcelain has a remarkably pure white surface, and is very thin and delicate. The Chinese value it highly, but no porcelain is now made in Corea (Janvier, p. 163).

According to the same writer, the Japanese paste is more fusible than the Chinese, and their porcelain is very translucent, owing to the fact that it contains more silica and less alumina than the Chinese or any other hard porcelain. It is also of a purer white body than the Chinese; the best qualities are very delicate, and are very carefully finished off. Hizen, Owari, Kioto, Tokio, and Kaga, are the principal places for porcelain in Japan.

The following are two other washed ingredients of Japanese porcelain, called "Shiro-chu-chi" and "Sakaime-chu-chi" respectively, analysed by Wurtz, which are given by Janvier, viz.:—

Silica	80·920	81·141
Alumina	15·822	14·542
Magnesia	0·100	0·242
Potash	0·530	0·999
Soda	1·530	1·789
Iron	0·932	1·060
Fluorine	0·152	0·195
Ox. manganese	0·014	0·031
	100·000	99·999

What these are, the writer cannot determine, but Janvier states (p. 148) that "according to careful investigations made at the time of the American Centennial Exhibition the finest Japanese porcelain seems to be made without the use of any kaolin at all, or of any equivalent therefor, being compounded as to its body solely of petuntze-like, or petro-siliceous materials," and suggests that similar materials might be found in the West to enable our porcelain manufacturers to rival the Oriental. Janvier is of opinion that the European china clay porcelain seems to be a new invention which must be classed by itself as a china clay (carclazite) body, whilst the Japanese and Chinese porcelains should be classed as felspar or petrosilex bodies, as might be found to be most correct; certainly, at present, little is positively known as to their composition. The Japanese, in their exhibit in Paris (1878), stated that *no kaolin was used in their porcelain.*

CHAPTER XIII

EUROPEAN AND CHINESE CLAYS COMPARED

FROM the statements quoted from various writers in this work it is obvious that some uncertainty at least exists, as to the absolute identity of our Cornish china clay (carclazite) with the Chinese kaolin; but as several authorities state that they are identical, and that any uncertainty that exists as to the composition of the ingredients of Chinese porcelain, relates more to the petuntze — assumed generally to be the fusible or fluxing ingredient of the body—than to the infusible clay ingredient, the writer will not discuss this question further until he treats of the Cornish china stone, when the whole question may be more satisfactorily reviewed.

Amongst other writers on kaolin, a prominent place must be given to Messrs. Johnson and Blake, who, after considerable research, and the examination, by aid of the microscope and otherwise, of a variety of plastic clays, found that many of them, including porcelain and pipe clays, and also some fire clays, possess certain chemical and physical properties which admit of precise definition, and that kaolin (china clay) possesses these most commonly and abundantly. These, and specially the latter, they found largely to consist of pearly hexagonal plates of the prismatic or trimetric system; and in a joint article in the *American Journal of Science*,[1] they proposed to rank all such as a distinct and new mineral species (of the genus *aluminum*), under the name of *kaolinite*, and their proposal has been adopted in the mineralogical department of the new Natural History Museum, South Kensington.

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[1] "On Kaolinite and Pholerite," by S. W. Johnson and John M. Blake, *American Journal of Science*, N.S., vol. xliii. 1867.

In the article referred to, Messrs. Johnson and Blake say, that kaolin is described by nearly all writers as an opaque amorphous substance. Some have mentioned it as containing minute transparent plates, but have supposed them to be mica or other admixture. They had examined "twenty specimens of kaolin, pipe, and fire clays—origin of most unknown. In all of them were found greater or less proportions of transparent plates, and in most of them these plates are abundant—evidently constituting the bulk of the substance." They further state that the "porcelain clay from Deindorf, Bavaria, is perhaps the most finely divided of all the white clays studied. When dusted on a glass slide it appears to consist chiefly of masses of a white substance that are opaque, or nearly so, in transmitted light, but, when fully illuminated above and below, they have the translucent aspect of snow in the lump. Interposed among these masses may be seen extremely minute and transparent plates of irregularly rounded outline. When placed in water, these masses are almost entirely resolved into similar transparent plates, most of which are not more than ·0001 of an inch in breadth. This description applies also to all the finer plastic clays."

In reading Messrs. Johnson and Blake's article, the writer was struck with the fact that those gentlemen had apparently not been able to procure and examine any specimen of the Chinese kaolin, however carefully they may have examined the porcelain and other clays of Europe and America; and yet they take for granted that the common belief, founded on the information furnished by Francis Xavier d'Entrecolles, nearly 200 years ago, is correct; and actually, on that mere supposition, they have proceeded to apply the Chinese term the European and American clays, which differ both in composition and origin from those of China and Japan. It is certainly a very unusual procedure so to fix scientific nomenclature on a doubtful basis, and it is to similar assumptions that all the uncertainty prevalent on the subject is due.

Messrs. Johnson and Blake quote the chemical formula first deduced by Forchhammer, from the analyses of a number of porcelain clays, viz., $4\,\ddot{\mathrm{Si}}$, $3\,\ddot{\bar{\mathrm{Al}}}$, $6\,\dot{\mathrm{H}}$, or $2\,\ddot{\mathrm{Si}}$, $\ddot{\bar{\mathrm{Al}}}$, $2\,\dot{\mathrm{H}}$, and they give the following analyses from that chemist of the porcelain clays on which he founds it, viz.:—

	From Richmond, Va.	From Zeisigwald, Sax.	From Altenberg, Sax.	From Freiberg, Sax.
Silica . . .	48·56	49·91	45·63	47·74
Alumina. . .	35·61	35·23	39·89	39·48
Water . . .	12·88	14·86	13·70	14·07
Impurities . .	2·95	0·00	0·60	0·00
	100·00	100·00	99·82	101·29

And they mention that they "found more than thirty analyses of clays, kaolins, and steinmarks, which obviously agree with the formula above given of crystalline kaolinite." They also state, that the first mention of a crystalline substance with the composition of Forchhammer's kaolin found by them, was "by Wöhler, who describes, under the name of steinmark (lithomarge—a variety of china clay), a pale, yellow, coherent mass, which is converted by dilute hydrochloric acid, with solution of a little oxide of iron, into a white shining powder. With the help of a lense, Wöhler found it to consist of shining laminæ, which, when magnified 200 diameters, were seen to be transparent, and to consist in part of rhomboidal plates. The mass had an earthy fracture which assumed lustre by rubbing, an unctuous feel, and adhered strongly to the tongue."

Messrs. Johnson and Blake also give an analysis of a clay from Schneckenstein, Saxony, by Professor W. S. Clark, of Amherst College, as follows, viz. :—Silica 46·76, alumina 35·59, water 13·42, impurities 0·94 = 96·71—sp. gr. 2·6 ; and mention that "this required to be acted on by hot concentrated hydrochloric acid for some time before falling to a white powder. Microscopical examination showed its close physical resemblance to kaolinite. It consists of plates and bundles of plates, the largest being ·0001 of an inch, or less, in breadth, and, when sufficiently magnified, showing a great similarity to the kaolinite from Summit Hill, Pa., U.S."

From the investigations of Messrs. Johnson and Blake, it may be taken that the basis of many of the china and other plastic clays is a soft, white, transparent, infusible substance, chiefly composed of very minute, flexible, hexagonal plates or laminæ, crystallised in forms probably belonging to the trimetric system. Its sp. gr. 2·6; lustre, pearly; insoluble in dilute hydrochloric acid; in most of its forms difficultly decomposed by hot concentrated hydrochloric acid, but resolvable by hot sulphuric acid, and dissolving completely in strong solutions of caustic alkalies ; and in chemical composition agreeing with the formula deduced by Forchhammer, from his analyses of various porcelain clays, as given above.

CHAPTER XIV

SOURCES OF IRISH PORCELAIN CLAYS

HAVING now pretty well exhausted the subject of these articles on clays; having mentioned the various varieties of clay, especially those in which some readers are more especially interested; having described their chemical composition and qualities, their origin and mode of occurrence in Cornwall and Devonshire, and also in various European localities; having also pointed out the difference between the pipe and potting clays of Devon and Dorset shires, naturally deposited in beds ready for use, and the *carclazite*, or true porcelain clay, of Cornwall and Devon obtained from the decomposed granitic rocks (known in Cornwall as "growan") by the various processes briefly described in a former chapter; having also given what little information is as yet available respecting the kaolins of China and Japan, and referred to the uncertainty still existing as to their being, as has been so generally assumed, really identical with the china clay of Cornwall and other European localities, I am anxious, to give some account of the china clays of Ireland and the rocks from which they are or may be obtained.

So far as the writer knows there are no indications of deposits of china clay being probably ever found in Scotland, although Bristow mentions its being found on the S.W. side of Fetlar,[1] one of the Shetland Islands. The writer cannot say, however, whether it exists in any quantity there, but, if it does, its distance and the extremely exposed and storm-ridden coasts of the Shetlands, renders it improbable that Fetlar will ever be looked to as a source of supply of china clay for our English potteries. The late Dr. Thomson, of Glasgow, who was a most enthusiastic mineralogist as well as chemist, and who devoted nearly all his spare time for ten years to the study and chemical analysis of rocks and minerals, especially those of Scotland, does not mention, in his work on Mineralogy, etc.,[1] either Fetlar, or any other place in Scotland, as a locality for china clay, nor does he mention any locality there for felspar (although felstone is abundant in many localities) or petrosilex—rocks from which it might be derived; and no subsequent Scottish geologist or mineralogist, so far as the writer knows, has indicated the probability of china clay being obtained in quantity there, or any at all elsewhere in Scotland; or the existence there of *pegmatite* or *protogene*, or any other variety of granitic rock, such as those from which, by decomposition, the soft "growan" of Cornwall is derived.

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[1] *Glossary of Mineralogy*, by H. W. Bristow, F.G.S. London, 1861. Under "Kaolin Localities."

This being so, should the question—as in the case of coal—ever be raised as to the probability of the exhaustion of the Cornish and Devonshire china clays, and as to where our porcelain manufacturers and potters can, in such an eventuality, look for the supply of that material, or a substitute for it, to keep their works going, the writer believes the reply must be—to that so long neglected but most important part of the United Kingdom, Ireland, which, if the sea that surrounds it be the "melancholy ocean," as designated by a lately deceased statesman, it is at all events a narrow one, speedily and safely traversed at all times, and, when crossed, revealing a country of magnificent harbours and inexhaustible water-power, and, indeed, a real El Dorado of metallic and mineral wealth of every sort, requiring only a modicum of common sense and submission to law on the part of its natives, and the thereupon speedy investment of capital, to develop its resources, and cause the "Emerald Isle" to smile with prosperity and wealth, by the development of mining and manufacturing industries, which might in time rival those of any other part of the kingdom at home or of the empire abroad; by which, along with the other remedial agencies now so effectually in operation, an end would speedily be put for ever to the agrarian violence that now disgraces it, and Irish hovels be changed into comfortable homesteads and their at present discontented inmates into prosperous and loyal subjects of His Majesty the King. May God thus, as well as in other ways, bless old Ireland!

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[1] *Outlines of Mineralogy, Geology, and Mineral Analysis*, by Thos. Thomson, M.D., Regius Professor of Chemistry in the University of Glasgow, 2 vols. London, 1836.

The writer has mentioned several localities in Ireland where there are deposits of pipe clay similar and equal in quality to those of Bovey Tracey in Devonshire, and the various Dorsetshire beds, and from some of which large quantities have been imported to England for potting purposes. So far as the writer has been able to ascertain, however, the chief localities in Ireland where porcelain clay occurs are Belleek, near Lough Erne, in the County of Fermanagh, where, according to Kinaghan,[1] there is a range of an endogenous granitic vein rock of pink orthoclase felspar, which is extensively worked by the Belleek Pottery Company, of which the writer hopes to give a more detailed account in a future article; Kilranehagh, near Baltinglass, County Wicklow, where china clay of a fine quality has been obtained; a locality a little S.E. of Westport, County Mayo, where a decomposed dyke of petrosilex forms a dyke of china clay; and Tullow, County Carlow, but where the porcelain clay is partly impregnated with iron. There are also masses of decomposed granite in the Mourne Mountains, County Down, which yield china clay; but of these localities, the available information, so far as regards their being future probable sources of supply of porcelain clay, is exceedingly scanty, and the writer is in hopes of having ere long an opportunity of personally ascertaining how far they are likely to be so.

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[1] *Manual of the Geology of Ireland*, by G. H. Kinaghan, M.R.I.A., of H.M. Geological Survey. London, 1878.

Little attention has, however, been paid as yet, and but little information is available, as to the extent of porcelain clay deposits in Ireland, or of the rocks which by their decomposition furnish it, and the writer cannot, from personal knowledge, say anything very definite on this point, but he believes that large supplies of this, as well as of pipe and other pottery clays, can be obtained from various of its counties. Dr. Kane[1] mentions that in many of the granitic districts of Ireland the felspar is found decomposed, and that, by means of the same artificial processes employed in Cornwall, porcelain clay can be obtained from it. It is not, however, so much to these he looks for future supplies of material for porcelain manufacturers, but to what he believes will be found to be inexhaustible sources of such material, viz., the extensive ranges of petrosilex occurring in many parts of Ireland, and which, so far as he can determine from the very scanty means available as yet in England for determining the subject, is identical with the chief material used for the manufacture of hard porcelain, both in China and Japan, in the latter of which country, if not in both, no such material as that generally called kaolin, and assumed to be identical with our English china clay, or carclazite, is used in the manufacture of Japanese porcelain (as mentioned on pp. 100, 101), nor probably (according to the statement of Baron von Richtofen, quoted on p. 95) in that of Chinese porcelain either.

Petrosilex is a very hard siliceous variety of felspar (of which only one very small specimen from China is to be found in the Jermyn Street Museum, as mentioned and described in a former chapter, by the use of which our porcelain manufacturers might probably produce a body rivalling in every respect that of the best Oriental manufacturers.

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[1] *Industrial Resources of Ireland*, by Robert Kane, M.D., 2nd edition. Dublin, 1845.

According to Kinaghan, dykes of petrosilex are specially numerous in Errisbeg, the country westward of Roundstone, County of Galway; while Warren recorded many of them in the area to the north of the Erriff valley, County of Mayo. They also occur in Wexford and neighbouring counties, in the vicinity of the granitic districts. There is, in fact, no doubt of the very extensive occurrence of this rock, and of the inexhaustible source it offers for the supply of this valuable material for porcelain manufacture.

CHAPTER XV

IRISH CLAYS—ANALYSIS—COMPARISON WITH JAPANESE CLAYS

IN now bringing these chapters on clays to a close, the writer regrets his inability to give further information regarding the materials existing in Ireland for the manufacture of porcelain, in which so very successful results have been achieved by the enterprise and taste of the Belleek Pottery Co., in County Fermanagh. The writer was indebted to Mr. Armstrong for information regarding the felspar and porcelain clay of that county.

Judging from the almost entire absence of Irish localities for it, in mineralogical works, the common orthoclase felspar, which has now to be brought all the way from Norway for our porcelain manufacturers, is of rare occurrence in Ireland. Bristow, for instance, gives only the single locality of Slieve Corra, Mourne Mountains, for it, and there apparently it occurs only in crystals, and not in the massive form; although the decomposed masses of granite in these mountains, which were referred to as yielding china clay, are doubtless derived from its felspathic constituent, and that may probably be orthoclase. As shown, however, in the last chapter, from Kinaghan, Ireland possesses numerous dykes of petrosilex, of identical composition to the one near Westport, County Mayo, mentioned by him as having by decomposition been changed into a dyke of china clay; and it has also numerous other varieties of felsites of similar composition.

The officers of the Geological Survey do not, as a rule, pparently consider it part of their duty to point out such rocks in Ireland as might furnish materials for technical purposes, but Jukes, in his *Manual of Geology*,[1] quotes analyses of petrosilex by Durocher, the mean of which is as follows:—

Silica	75·40
Alumina[2]	15·00
Potash	3·10
Soda	1·30
Lime	0·80
Magnesia	1·10
Oxides of iron and manganese	2·30
Loss	1·00
	100·00

Now this bears so remarkable a resemblance to the mineral which Dr. J. Hoffman, in his description of the porcelain quarries of Japan, describes as white and hard as rock, and which the Japanese, he says, break with hammers and pulverise in mills as an ingredient of their porcelain, that, for convenience of contrasting them, it may be as well to repeat here Malagetti's analysis of it, quoted by Janvier, and given in a former article, viz.:—

Silica	75·09
Alumina	20·00
Potash	3·05
Lime	0·06
	98·20

The writer will not presume to say whether this mineral is the kaolin or the petuntze of the Chinese and Japanese porcelain manufacturers, but it is undoubtedly one of the two; and whichever of the two it is, it is not got, like our china clay, from a decomposed rock, but is reduced from a hard siliceous rock to a fine powder, for an ingredient of porcelain, by the processes just referred to, and which, as previously mentioned, are also the processes by which the hard mineral "Yeon-ko" is prepared by the Chinese for their porcelain bodies.

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[1] *The Student's Manual of Geology*, by J. Beete Jukes, M.A., F.R.S., Local Director of the Geological Survey of Ireland. Edinburgh: A. & C. Black, 1862.

[2] Another analyses gives 18·00, which makes the resemblance to the Japanese mineral still closer.

In closing these chapters on porcelain clays, I beg leave to state my belief that the enterprising porcelain manufacturers of England would do well to direct their attention to the petrosilex and other highly siliceous felsites of Ireland, for the purpose of still further rivalling, if not excelling, the best porcelain bodies of the Japanese, who are at present unrivalled in the higher productions of their art.

These chapters being limited to clays as potting materials, the writer considers it unnecessary to describe the various uses to which pottery clays, and especially china clays, are now so extensively used in numerous other manufactures and manufacturing processes, and there is the less need for his doing so, as this information is given in numerous cyclopædias. It is certainly a subject of very great and increasing interest, as the varied applications of these clays to technical purposes are constantly expanding, and likely to be indefinitely increased.

The opinion of the mineral and metallic wealth of Ireland, expressed by me on p. 112, may doubtless appear to some readers an exaggerated one; but while I purposely state my opinion strongly, in the hope of directing the attention of my readers to that part of the United Kingdom, I have not done so without good grounds. In a list, published in Dublin for H.M. Stationery Office in 1854, of localities in 29 counties of Ireland, in which mines and metalliferous indications and minerals had been discovered previous to that date (now thirty years go), there are no fewer than 238 localities for lead — in nerous cases rich in silver; 209 for copper, one having e copper; 34 for zinc; 37 for clay ironstone, and other iron ores, including hematite; 11 for silver and auriferous silver ores; 5 in which gold (formerly very abundant in Ireland) is found, and 2 of auriferous gossans; 7 for antimony; 3 for tin; 1 for bismuth; 1 for arsenic; 2 for cobalt; 11 for manganese; 8 for sulphate of barytes; 5 for mundics, and 30 for sulphur ores—a list which could now be greatly extended, apart altogether from its deposits of rock salt, gypsum, soapstone, bog iron ores, now so extensively used for the purification of gas, and valuable limestones and marbles, slates, granite, and other building stones, and its extensive beds of pipe and china clays, fire clays, and coal. There is an abundance of corroborative testimony as to these, to be had by those who will take the trouble to inquire; and there can be no doubt entertained, by those who do so thoroughly, that security for the investment of that capital, which is now almost becoming a drug in Lombard Street and the City, is all that is wanting to develop these abundant metalliferous mineral deposits of Ireland, and thereby revolutionise the condition of that country, by providing remunerative employment for thousands and tens of thousands of its at present half-starved and pauperised population.

CHINA STONE

CHAPTER XVI

COMPOSITION—OCCURRENCE—ANALYSES

CHINA stone, or, as it is sometimes called, Cornish stone, from its being obtained from Cornwall, and there only in the United Kingdom, is a granitic rock, chiefly composed of white or pale brown quartz and white felspar, with occasionally a little light yellowish or greenish *gilbertite* and also flakes of *lepidolite*, a white lithia mica — neither of which, if only in very small quantities, injure the economic value of the stone; but when it contains any larger quantity of either, or of brown or black schorl, it is useless for potting purposes. It is essentially a quartzose felspathic rock—the quartz, however, being much in excess of the felspar, and the latter often in a more or less decomposed condition. The best qualities of the stone contain fluorine, which greatly increases its fusibility, and that of St. Stephen's, which contains a considerable proportion of it, is in consequence much preferred by potters. The felspar of the stone is chiefly *orthoclase* (potash felspar) with a little *albite* (soda felspar).

China stone varies much in hardness, and, while its constituent felspars are usually more or less decomposed by tmospheric and other agencies in the "stone" supplied to the tteries, its harder varieties are pretty durable, and, being ly wrought, they are much used locally for building pur-especially in the St. Stephen's district, where it is chiefly worked, and has long been largely employed for building purposes, not only for dwelling-houses, and farm-steadings, etc., but also for churches—the fine towers of St. Stephen's and Probus Churches may be cited as examples of its adaptability and durability for public buildings; and in the neighbouring districts it is largely used and known by the name of "St. Stephen's stone."

In Cornwall the china stone is produced by the partial decomposition of *pegmatite*, by atmospheric influences, and that of hydro-fluoric acid, which is never absent and is generally derived from *lepidolite* and other fluorine minerals. *Pegmatite* is a binary granite, composed chiefly of quartz and felspar with more or less fluorine—the felspar lying impacted in the quartz, as crystals or otherwise, as in a matrix, with more or less of the silvery white mica — and often passing into *graphic* granite. Some writers, however, describe the "stone" as being produced by the decomposition of *protogine* (Gr. *protos*, first, and *ginomai*, I am formed, and so named under the erroneous idea of its being the *first-formed* of all the granites), the French term for talcose granite, composed of quartz, felspar, and talc; but Collins says, in his monograph,[1] "All the old writers speak of talcose granite, or *protogine*, as being abundant in the decomposed granite distric of Cornwall and elsewhere. What there may be elsewhere, I am not able to say, but there is certainly nothing of the kind at present known in Cornwall"; and as from his intimate knowledge of that county, and his special study of its granitic rocks, he is a most reliable authority on the question, the latter opinion of the source of Cornish stone may be dismissed from consideration.

China stone is now generally considered to be identical with the Chinese *petuntze*. That name, however, is a singularly unfortunate one, its literal meaning being "little white brick"

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[1] *The Hensbarrow Granite District*, by J. H. Collins, F.G.S. Lake & Lake, Truro, 1878.

(*pe*, white, *tun*, brick or block, and *tze*, little), and the other or infusible ingredient of their porcelain being also made up into similar white bricks.

This infusible ingredient, similar in character but of a different origin to our china clay, or kaolin, being obtained either from the natural decomposition, or by the complete artificial pulverisation by stamps, of a variety of *petrosilex*, a very hard, compact, siliceous felspar, called by the Chinese caulin (*kao-ling*—Chinese for *high ridge*), from a high ridge where it was first discovered, and from which it was conveyed (till some centuries ago, when the rock there was exhausted) for the supply of the numerous potteries of King-te-chin in the form also of small bricks. These bricks may probably have some distinguishing mark or stamp impressed upon them, but whether so or not, the similarity of their appearance has doubtless something to do with the confusion caused by travellers or writers having repeatedly confounded the one with the other. The two terms, however, *kaolin*, for porcelain or china clay, and *petuntze* for china stone, have now definitely been adopted in the Keramic nomenclature of Europe.

It may be as well to mention here, in passing, that a similar petro-siliceous rock occurs abundantly in Ireland, in the form of irruptive dykes, which are in some localities found decomposed by atmospheric agency, *in situ*, into the finest china clay. Even where they are not so decomposed, they could furnish, by the use of stamps or grinding mills, an unlimited supply of the finest porcelain clay, and will doubtless do so when capital can safely be invested in that unfortunate country.

Janvier says that the "Chinese and Japanese porcelains are like composed of a fusible and transparent, and an opaque and sible, substance — the former, a quartzose felspathic rock, ed to deprive it of its water of crystallisation, and then reduced to a fine powder, is the *petuntze*; the latter, the *kaolin*—

> "Grind with strong arms, the pond'rous chert betwixt,
> The soft *kaolin*, with *petuntze* mixed."

As the composition of the latter rock, or china stone, varies considerably, it is advisable for the manufacturers of porcelain to ascertain, by an analysis of each lot, in what proportion the ingredients stand to each other. The Chinese use a flux with it, which they call "*oil*," and which is a thin paste of lime and potash, the latter principally obtained from the burnt fronds of ferns.

Collins, in his monograph already quoted, gives the undernoted analyses of china stone, Nos. 1 and 2 being the *mean* of two analyses of each sample, viz. :—

	No. 1.	No. 2.	No. 3.
Silica	73·39	69·50	71·66
Alumina	16·50	17·85	18·79
Potash, with a little soda . .	7·66	7·98	6·60
Fluorine	0·74	0·71	0·14
Lime	0·50	2·66	1·70
Magnesia	0·31	0·12	0·35
Iron, only a trace . . .	—	—	—
Water and loss	1·25	1·30	0·91
	100·35	100·12	100·15

Collins, who, in his monograph, proposed the name of *carclazite* as a specific name for the china clay of Cornwall, says therein, "Such an important rock as china stone ought also to have a specific name," and proposed that of *petuntzite*, —and it is certainly desirable that both these names should be brought into use for general, or at least scientific, purposes. Owing to its large proportion of silica and potash with other alkaline ingredients, china stone is invaluable as a fluxing material, and is generally used in the potteries in the manufacture both of earthenware and porcelain, being mixed, in varying proportions, after being reduced by grinding in water to a fine slip, with those of the clays and flint, which constitute the various bodies of these manufactures.

CHAPTER XVII

CHINA STONE—DISCOVERY AND USES

SOME obscurity still exists as to the relations between china stone (*petuntzite*) and the china clay granite (*carclazite*), although it is asserted by some writers, and indeed is generally assumed, that they are both products of one species of granite rock, differing only in the stage of decomposition in which they are found. *Petuntzite* being that granite so little affected by atmospheric and other agencies of decomposition as to remain hard, compact, and durable, in which state — as mentioned in the previous part of the last chapter — it is largely employed as a building stone; and even where occurring so much decomposed as to be easily broken down, when being quarried for export to the potteries, still retaining more or less of the alkaline ingredients of its constituent felspars, to which it owes its special value for employment in the manufacture of earthenware and porcelain. Then, when these felspars are thoroughly decomposed, the rains wash out the greater portion of their soluble alkalies, which are carried off to enrich the soil of the underlying valleys, leaving *in situ* the more or less pure silicate of alumina, which constitutes the china clay of Cornwall. This, whether occurring as a deposit *in situ*, or washed down and re-deposited in lower hollows of the granite range, is mixed with more or less of the quartz, mica, schorl, etc. (originally contained in the undecomposed granite), from which it is subsequently freed by artificial water action in its preparation for potting, and the various other manufacturing processes for which it is now so largely employed.

While, however, as above mentioned, it is generally assumed that both the china stone and clay are the products of the same species of granite, there are some phenomena connected with the occurrence of the former in various places, such as St. Stephen's, St. Dennis, St. Austell, and others in the Hensbarrow granite district of Cornwall, which seem to indicate some specific difference between them. In the above district the china stone occurs in irregular patches, bands, and dykes in the granite, and, unlike the *carclazite*, or china clay rock, it does not appear to be necessarily connected with veins of schorl and other materials which are more or less largely characteristic of the latter; and as regards decomposition, it appears to occupy an intermediate position between it, on the one hand, and the hard, unaltered granite on the other. While *carclazite* also occasionally passes into *petuntzite* in depth, and more frequently in horizontal extension—and Collins states his belief that the latter is never found unconnected with the former — yet there are instances where, as for example at Little Treviscoe, in the parish of St. Stephen's, the china stone is found *above* an underlying mass of *carclazite*, and were there not some specific difference in the composition of their constituent felspars, it is difficult to understand how the latter could have been decomposed, while the former remained unaltered or undecomposed—both being subjected to the same decomposing agencies, and which naturally and generally decompose the overlying masses first. Again, sometimes crystalline masses are found enclosed in the china stone, having the appearance and composition of yellow mica, and yet the figures of these masses are those of a triclinic felspar, not found associated with the *carclazite*. Occasionally, too, ystals of undecomposed or partially decomposed felspars of rent species occur in the "stone." Seen at a little distance, there is little difference in the appearance of *petuntzite* and *carclazite*, and in Professor Sedgwick's description of the district where they chiefly occur,[1] it is evident that he misunderstood what he saw, and confounded the two; for, speaking of the decomposed granite, he says: "On a near examination it is found soft enough to be cut with a spade, and it is in that state packed up and exported to the potteries. In other pits on the same moor the rock is broken down by mechanical force, and a running stream of water is made to pass through the fragments, the beautiful white china clay resulting from this process." Collins, in his monograph already quoted, says that Dr. Fitton, who visited Cornwall in 1814, observed the facts somewhat more accurately than Professor Sedgwick, for he observed that most china clay works there had a stone quarry, and the "stone" is often so hard as to require wedging or blasting in quarrying it, the hardest being generally preferred as easiest for conveyance.[2] If it is taken a fathom or so from the surface, where it is quite solid, it is stained with an abundance of greenish spots—probably of fluor spar—a peculiarity which was noted in the Chinese *petuntze* by the Jesuit Father d'Entrecolles, who, when writing on Chinese potting materials in 1712, stated that such stones as had most of these greenish spots were the most proper for the preparation of the glaze; and Mr. Worth, in a paper on "William Cookworthy and the Plymouth China Factory,"[3] says: "I believe this remark is just, as I know that such stones are the most easily vitriable, and that a vein of it in Tregonning Hill, in the parish of Germoe, is so much so, that it makes an excellent glaze without any addition of vitrescent ingredients."

The discovery of china stone in England, and its first employment for potting purposes there, is universally credited to Mr. William Cookworthy, a member of the Society of Friends.

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[1] Vide *Cambridge Philosophical Transactions*, vol. i. pp. 404-5.

[2] Vide *Annals of Philosophy*, 1814, vol. iii. p. 181.

[3] *Transactions of the Devonshire Association*, July 1876.

He was born in Kingsbridge, in South Devon, on 12th April 1705, and established a pottery at Plymouth in 1733, in which he must at first have made only common earthenware, or otherwise have imported china clay from the Continent. He appears to have commenced a search for porcelain clay and china stone in England, in 1745, in consequence of his attention having been directed to these materials by an American, who submitted to him specimens of both which had been found in Virginia, and also of porcelain made from them. After a long personal search for similar materials, during which he rode over large tracts of Devonshire and Cornwall, his perseverance was rewarded by their discovery in the latter county. It has been said that Cookworthy first discovered *petuntzite* in the stones of the tower of St. Columb's Church, which was built of the "stone" from St. Stephen's, and that he identified it as similar to that shown to him by the American. His own account of it is, however, given in a letter of date 30th May 1745, quoted by Mr. Worth, in which he mentions having seen the specimens brought by an American from Virginia, and which he considered identical with the Chinese porcelain materials, specimens of which had been brought to Europe in 1712. He stated that "he first discovered the china stone in Tregonning Hill," and described it as "composed of small pellucid gravel (quartz) and a whitish material, which indeed is *caulin* (kaolin) petrified (evidently the partially-decomposed felspar), and as the *caulin* of Tregonning Hill hath abundance of mica in it, this stone hath it also." Then he goes on to describe the greenish spots in it, and its vitrescent qualities, as already mentioned above. He further mentions having chiefly employed the "stone" from Tregonning Hill in his factory, but that he had lately discovered that in the neighbourhood of St. Stephen's in Cornwall there were immense quantities of both the *caulin* and the *petuntze*, which he believed might be more commodiously and advantageously wrought than those of Tregonning Hill, and by experiments he had made with them, he found "they produced a much whiter body, and do not shrink by far so much in baking, nor take stains so readily by the fire." "The parish of St. Dennis, too," he believed, "contained both these materials in plenty." "I know," he adds, "two quarries of the 'stone,' one just above St. Stephen's (Church Town), the other, called Caluggas, somewhat more than a mile from it, appears to have the finer 'stone.'"

In the specifications for a patent for the employment of the china stone and clay in the manufacture of porcelain, by Cookworthy, granted in 1755, and renewed in 1768, he claims the discovery of both in England, as his own, and calls the stone *growan* and *moor-stone*, and the clay *growan-clay*.

The china stone requires but little preparation for market. The overburden is removed, and the stone roughly quarried, and where the rock is traversed by numerous joints, which it generally is, this is easily effected and usually without blasting, which is, however, sometimes necessary. Very few of the pits or quarries are worked to any great depth, seldom more than 10 or 12 fathoms, as the upper stone is worked at much less cost than the underlying, and few of the pits have any facilities for deep drainage by adit levels. The joints of the "stone" are usually discoloured by green vegetable stains, brown ones, due to oxide of iron, or black ones, due to oxide of manganese. The stones are dressed by chipping with an axe, by which they are freed from most of these stains, and in the large potteries (or in the flint mills which supply it ground, in the liquid or dried state, to the smaller factories), it is finely ground in water to the consistency of cream, and mixed in due proportions with the flint and clay slips for the various bodies for which it is now so generally employed.

From the following analysis of *Tsuji-chu-chi*, a Japanese porcelain stone—

Silica	80·672
Alumina	16·174
Soda	1·799
Potash	·569
Magnesia	·102
Ferrous oxide	·684
Manganese	trace
	100·000

it will be noticed, by a comparison of it with the analyses of china stone, that while it has a larger percentage of silica, it is deficient in the alkalies, having 2·368 of soda and potash combined, whereas the average of these in the three analyses there given is 7·413. This is doubtless the reason why the Oriental porcelain manufacturers have to add a flux of lime and potash to their ground *petuntzite*, as mentioned in the former part of this chapter.

It may be mentioned that while only 10 per cent. or so of the china clay of Cornwall is exported for employment in potting, the whole of the china stone exported is solely for that purpose.

THE END

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